Appendix A

Biological Relationships

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1.0 INTRODUCTION

Currently, the Fish Passage Model functions by using a series of equations that represents a sequence of events occurring during the Chinook salmon life cycle. The biological element equations on the Fishery User Input Values page of the model could be considered to be a series of transactions where loss of a proportion of the population occurs. The input values were derived from those reported in the literature, and were termed “Biological Relationships.”

The Biological Relationships, below, provide the definition of each biological element input value on the Fishery User Input Values page of the model and technical terms associated with each input value, assumptions made about each biological element input value, and the relationship of each input value to the literature. Each Biological Relationship provides reported values, or ranges of values that were used to determine the best case, expected, and worst case value in each of the biological element input values.

2.0 SPAWNING

2.1 PRE-SPAWN SURVIVAL RATE

Definition of Terms

- Pre-spawn Survival Rate is the complement of pre-spawn mortality rate, which is defined as the percentage of female adult Chinook salmon transported to the tributaries upstream from Lake Oroville that die prior to spawning. That is, the Pre-spawn Survival Rate is the percentage of female adult Chinook salmon transported to the tributaries upstream from Lake Oroville that survive to spawn.

- Pre-spawn mortality is defined as the proportion of females transported and released into the upstream tributaries that die prior to spawning and includes, but is not limited to, in-river mortality caused by transport, or any other immigration or handling related stress (latent mortality), water temperature-dependent mortality, disease-induced mortality, predation of adults prior to spawning, angler induced mortality, and competition between spawning adults sufficient to preclude some fish from spawning.

Assumptions

- Spring- and fall-run Chinook salmon pre-spawn survival rates are similar.

- Water temperatures recommended by regulatory agencies, including NOAA Fisheries and DFG, protective of Chinook salmon during adult upstream immigration and holding will be provided in the Feather River tributaries to Lake Oroville.

- Angling pressure in the upper Feather River tributaries will be limited during the adult Chinook salmon in-river residence period prior to spawning.

- During spring-run Chinook salmon adult holding in the upper Feather River tributaries, angling restrictions would be implemented to minimize pre-spawn mortality rates.

Biological Justification

Pre-spawn mortality rates are usually low, but can vary across regions and through time. Shepard (1975) *in* Healey (1991)) reported a 19.1 percent pre-spawn mortality estimate for Bear River Chinook salmon, and that 30 of 230 female Chinook salmon (13%) observed in the Babine River died unspawned. In 1965, approximately 25 percent of Chinook salmon in a spawning channel at Priest Rapids, Washington died prior to spawning, reportedly due to a protozoan infection of the gills (Pauley (1965) *in* Healey (1991)). In 1988, DFG reported that pre-spawn mortality of Trinity River

Chinook salmon ranged from a high of 75 percent at the beginning of the spawning season, to a low of 23 percent in the final weeks of the spawning season (Zuspan et al. 1991). The overall female Chinook salmon pre-spawn mortality rate during the survey period was 44.9 percent. The percentage of females that died prior to spawning in the American River reportedly ranged from 3 percent in 1993 to 19 percent in 1995 (Williams 2001).

Pre-spawn mortality estimates were calculated for the lower Feather River by linear regression analysis of carcass survey data collected from the 2000 through 2002 Chinook salmon spawning seasons in the lower Feather River below the Fish Barrier Dam. Study Plan Report SP-F10 Task 2B summarizes the survey protocol and statistical analyses performed to derive pre-spawn mortality estimates. In 2000, average pre-spawn mortality for the entire spawning season was estimated to be 33.0% in the LFC and 38.8% in the HFC. In 2001, average pre-spawn mortality for the entire spawning season was estimated to be 50.8% in the LFC and 39.1% in the HFC. In 2002, average pre-spawn mortality for the entire spawning season was estimated to be 46.5% in the LFC and 29.2% in the HFC. From 2000 through 2002, the pre-spawn mortality estimate in the LFC and HFC averaged 43.4 and 35.7 percent, respectively. The average pre-spawn mortality rate combining all study years and both reaches was 39.6 percent (DWR 2004).

Recent surveys in Central Valley rivers with large hatchery-produced spawning populations and limited spawning habitat show high adult pre-spawn mortality. From 2000 through 2002, pre-spawn mortality averaged 39.6% percent in the lower Feather River (DWR 2004). Adult pre-spawn mortality rates were reported to be 60% and 87% on Battle Creek in 2002 and 2003, respectively (pers. com. C. Harvey-Arrison, 2004). In the lower American River pre-spawn mortality reportedly was at least 37% in 2003 and could potentially have been higher if partially spawned fish were included in the assessment (Healey 2004). Although the cause of the high adult pre-spawn mortality in these rivers is unclear, it appears to be related to large numbers of hatchery fish stressed by angling pressure and competition for limited spawning habitat. This interpretation is supported by much lower observed pre-spawning mortality in rivers with lower densities within spawning populations. Adult pre-spawn morality in the Yuba River, for example, reportedly was less than 4% in 2003 (pers. com. S. Theis, 2004). T. Hayne, (2004) reports that pre-spawn mortality in tributaries to the San Joaquin River (Tuolumne, Stanislaus and Merced Rivers) typically are 5% or less. In the Sacramento River, adult pre-spawn mortality for fall and late-fall-run Chinook salmon reportedly were as high as 13% in 1996, but was between 3% and 8% in other years (Snider B. et al. 2000; Snider et al. 1999).

The results from Central Valley rivers without large populations of hatchery fish spawning in-river suggest that adult pre-spawn mortality rates can be expected to be relatively low as long as stressors such as high water temperatures, crowding and intense angling pressure are minimal. Because these conditions are consistent with the assumptions of this modeling exercise, the input values for adult pre-spawn survival should be relatively high. Based on the suite of data from comparable local river systems pre-spawn survival values of 97 percent, 95 percent, and 90 percent were chosen for best case, expected, and worse case scenarios, respectively.

2.2 REDD SIZE

Definition of Terms

- Redd Size is defined as the area of substrate disturbed, and thus utilized, by a spawning female adult Chinook salmon.

Assumptions

- Redd size is not related to fish size.
- Redd size does not differ between spring-run Chinook salmon and fall-run Chinook salmon.
- Adult female Chinook salmon construct only one redd per spawning event.
- Adult female Chinook salmon spawn only once.

Biological Justification

Specific river mean redd size is typically quantified through field measurement or by aerial photograph interpretation. When these options are not available, literature reviews are conducted to estimate the mean and range of redd sizes of the same salmonid species and race in other river systems for use as a surrogate. The mean dimensions of Chinook salmon redds vary geographically and between runs (Healey 1991). Differences in the reported mean size of Chinook salmon redds also may be a function of measurement methodology (Healey 1991). For example, field measurements might lead to smaller redd areas than measurements obtained from aerial photographs due to difficulties in the field identification of the tail spill and head of newly constructed redds, particularly if the redds are irregularly shaped (Snider and Vyverberg 1995).

Using field measurement techniques, Burner (1951) reported a grand mean size for fall-run Chinook salmon redds of 53.5 ft^2 and a range from approximately 42 ft^2 to 70 ft^2 for three tributaries of the Columbia River. Using similar techniques, Chapman et al. (1986) reported a grand mean size for fall-run Chinook salmon redds of 184.1 ft^2 and a range from approximately 22.6 ft^2 to 482 ft^2 in the Hanford reach of the Columbia River (Chapman et al. 1986). Field measurements and aerial photography were used to delineate mean redd size of fall-run Chinook salmon in the American River (Snider and

Vyverberg 1995). The grand mean size of redds calculated from field measurements and aerial photographic interpretation was reported as 33 ft^2 and 190.5 ft^2 respectively. Healey (1991) calculated redd areas from dimensions provided by Vronskiy (1972) from the Kamchatka River. Redd areas were obtained by multiplying the maximum and minimum measurements of redd lengths and widths. Based on the measurements taken by Vronskiy (1972), Healey (1991) reported redd areas ranging from 43 ft^2 to 161 ft^2. Nielson and Banford (1983) *in* Healey (1991) reported redd sizes ranging from 5.4 ft^2 to 296 ft^2 with an average redd size of 102 ft^2 using maximum length and width calculation techniques. Moyle (2002) reported that redd areas for Chinook salmon ranged from approximately 22 ft^2 to 108 ft^2. During studies conducted to determine the factors affecting Chinook salmon spawning in the Feather River, Sommer et al. (2001) calculated superimposition rates utilizing a redd area provided by Bell (1986). Sommer et al. (2001) reported that 55 ft^2 was, "*the average surface area for an average size fall-run Chinook salmon*."

For this model, redd size is a part of the calculation of redd superimposition rates and because higher redd superimposition rates are considered to have larger negative impacts on juvenile salmon initial-year-class strength, the best case redd size is considered to be the low endpoint of the range of reported redd areas. Conversely, the worst case redd size is considered to be the high endpoint of the range of reported redd areas. Therefore, utilizing the best case redd size would result in the lowest superimposition rates given a fixed spawning area and number of spawning adults, and the worst case redd size would result in the highest superimposition rates given a fixed spawning area and number of spawning adults. The best and worst case redd sizes were calculated by taking the mean of the respective endpoints of the ranges of reported redd areas reviewed. Therefore, the low end of the reported range of redd sizes provided by Burner (1951), Chapman et al. (1986), Vronskiy (1972) *in* Healey (1991), Nielson and Banford (1983) *in* Healey (1991) and Moyle (2002) were used to calculate the best case redd area for Lake Oroville tributaries while the high endpoints of the ranges provided by these authors were used to calculate the worst case redd area. Because sampling methodologies and redd area quantification techniques were not standardized between reports reviewed, using the mean of the low endpoints of the reported ranges of redd size was considered appropriate.

Calculation of best case redd size based the ranges of redd size reported by Burner (1951), Chapman et al. (1986), Vronskiy (1972) *in* Healey (1991), Nielson and Banford (1983) *in* Healey (1991) and Moyle (2002) resulted in a best case redd size in the tributaries to Lake Oroville of 27 ft^2. Worst case redd size was calculated to be 223 ft^2.

Because superimposition rates have been calculated by Sommer et al. (2001) in the lower Feather River based on the average redd size of spawning fall-run Chinook salmon, 55 ft^2 was chosen as the expected average redd size for the tributaries to Lake Oroville. Utilization of the same redd area as Sommer et al. (2001) allows for redd superimposition rates to more accurately be compared between the lower and upper

Feather River than if redd areas from other studies were used to determine the expected redd size. Additionally, comparison of superimposition rates between the upper and lower Feather River could aid decision makers in determining the appropriate number of female adult Chinook salmon to transport above Oroville Dam.

Based on reported redd areas from multiple studies, best case, expected, and worst case Redd Size is 27 ft^2, 55 ft^2, and 223 ft^2, respectively.

2.3 EGG PRODUCTION PER FEMALE

Definition of Terms

- Egg production per female is defined as the average number of viable eggs produced per female adult Chinook salmon.

Assumptions

- Water temperatures and other environmental factors in the upper Feather River tributaries are appropriate to allow average egg production per female.

- Angling restrictions would be enforced to minimize stress and the potential for egg retention in spawning adult female Chinook salmon.

Biological Justification

Using a regression model developed to predict Sacramento River spring-run Chinook salmon fecundity, DFG (1998) estimated that female spring-run Chinook salmon produce between 1,350 and 7,193 eggs per female with a weighted average of 4,161 eggs per female (DFG 1998; California Department of Fish and Game website).

In addition to DFG estimates, Feather River Chinook salmon egg production from 2001 through 2002 in the Feather River hatchery was examined. According to hatchery records, female Chinook salmon produced an average of 6,000 eggs per female and 5,662 eggs per female in the 2001 and 2002 spawning runs, respectively. Average egg production reportedly was calculated by dividing the estimated total number of eggs retrieved by the total number of females spawned (Kastner 2002; Kastner 2003).

Although the number of eggs retrieved during hatchery operations provides reasonably accurate estimates of the average number of eggs produced by adult female Chinook salmon, the estimates do not necessarily reflect the number of eggs deposited in the gravel by wild spawning females (California Department of Fish and Game website; Healey 1991). It has been reported that egg retention represents an important potential loss in egg production (Healey 1991). Egg retention rates ranging from 0.5% to 1.3% were reported for spawning female adult Chinook salmon, however estimates of 20% to

25% were reported in females that were harassed (Vronskiy 1972, Major and Mighell 1969, and Shepherd 1975 *in* Healey (1991). Egg retention rates of 25% also have been reported in adult female Chinook salmon with gill infections (Pauley 1967 *in* Healey (1991). A mean egg retention estimate of 0.8% was calculated based on the reported range of egg retention estimates obtained from healthy, unstressed adult female Chinook salmon.

For modeling purposes, hatchery calculated estimates of Feather River Chinook salmon egg production were considered representative of the upper Feather River tributaries. Additionally, the calculated mean egg retention estimate of 0.8% was subtracted from the reported range of average number of eggs produced per female for Feather River Chinook salmon to obtain the best case and worst case egg production for the upper Feather River tributaries. The estimate of mean egg retention was subtracted from the mean number of eggs produced per Feather River Chinook salmon female, calculated by averaging the egg production estimates from the 2001 and 2002 spawning runs, to obtain the expected egg production for the upper Feather River tributaries. Therefore, for modeling purposes, the best case, expected, and worst case Egg Production Per Female is 5,520, 5,365, and 5,209 eggs.

2.4 SUPERIMPOSITION MORTALITY RATE

2.4.1 Definition of Terms

- The redd superimposition rate is the percentage of previously constructed Chinook salmon redds that are subjected to disturbance by subsequently spawning females.

- The Superimposition Mortality Rate is the percentage of eggs in a redd that suffer mortality due to being superimposed upon by another redd.

2.4.2 Assumptions

- Redds are either fully superimposed upon or not; no partial superimposition occurs.

- Superimposition rates of spring- and fall-run Chinook salmon are the same.

- Each adult female Chinook salmon constructs only one redd.

- All available spawning habitat is utilized before superimposition begins to occur.

- Redd size is 55 ft^2.

2.4.3 Biological Justification

Redd superimposition occurs when female salmonids construct redds on top of previously constructed redds. Superimposition rates are a function of spawning density, streamflow, available spawning habitat and other factors. High rates of superimposition typically occur in river systems where spawning habitat is limited Fukushima (1998).

In the Low Flow Channel (LFC) of the lower Feather River, Chinook salmon reportedly used 773,732 ft^2 for spawning, with the greatest area concentrated just below the Fish Barrier Dam. The uppermost three miles of the LFC contained more than 60 percent of the defined spawning area. The majority of spawning occurred in riffles and glides. The LFC spawning escapement estimate based on the carcass survey by DFG in 1995 was 44,111. The estimated superimposition index in the LFC was 1.57 (Sommer et al. 2001). Theoretically, a superimposition index of 1.0 represents no superimposition. The superimposition index results are similar to those reported by Painter (1977). The high superimposition indices calculated for the LFC suggest that spawning habitat in this reach is limiting (Sommer et al. 2001). In the High Flow Channel (HFC), Chinook salmon reportedly used 1,480,085 ft^2 for spawning. Areas used for spawning were evenly distributed throughout the HFC, with glide habitats used most extensively. The HFC spawning escapement estimate based on the carcass survey by DFG in 1995 was 15,572. The estimated superimposition index in the HFC was 0.47 (Sommer et al. 2001). The results are similar to those reported by Painter (1977).

Redd superimposition may result in incubating egg and alevin mortality (Healey 1991). In Auke Creek, Alaska, maximum daily egg loss for pink salmon resulting from redd superimposition was estimated to range from 278,000 to 398,000 eggs (Fukushima 1998). During 1963 and 1964, a 46 percent egg mortality rate was reported for pink salmon due to superimposition by chum salmon in the Qualicum River, Canada (Walker and Lister 1971).

Reported results from Kindopp (1999) suggest that redds constructed later in the spawning season have higher survival rates. One possible explanation for this observation is that redds constructed later in the spawning season may be less likely superimposed upon. However, differences in early and late spawning season water temperature also likely would affect egg survival rates.

Sommer et al. (2001) reported that historical data from the lower Feather River suggest that superimposition significantly reduces egg survival. Within the LFC of the lower Feather River, egg survival is reportedly reduced as a result of superimposition (Sommer et al. 2001). The average egg survival rate below Thermalito for 1968 through 1972 was reported to be 84 percent. The highest survival rate for Chinook salmon eggs in the LFC was reportedly 93 percent (Sommer et al. 2001). Egg survival rates for the Feather River from the Fish Barrier Dam to the Thermalito Afterbay Outlet reportedly ranged from 93.5 percent in 1968 to 31.6 percent in 1969. However, in some years spawning was reported to be so intense that it was difficult to identify individual redds; most were contiguous or obviously superimposed (Painter et al. 1977).

Superimposition is probably one of the key factors driving Chinook salmon egg mortality in the Feather River (Kindopp 1999). The high density of spawners in the upper three miles of the Low Flow Section creates extreme competition for quality habitat resulting in high superimposition. Potentially further exacerbating Chinook salmon redd superimposition is the armoring of spawning gravels in the LFC, further reducing the available spawning habitat.

Literature was not located regarding the mortality rates incurred by incubating eggs and alevins in redds superimposed upon by subsequently spawning female Chinook salmon. Therefore, an estimate of the Superimposition Mortality Rate could not be determined through literature review. For modeling and analysis purposes, a Superimposition Mortality Rate of 20 percent was arbitrarily selected. Each incidence of redd superimposition results in 20 percent mortality of the incubating eggs or alevins. A second incidence of redd superimposition results in an additional 20 percent mortality incurred by the original redd, and 20 percent mortality to the second redd.

2.5 IN-RIVER EGG TO SMOLT SURVIVAL RATE

Definition of Terms

- In-River Egg to Smolt Survival Rate is the percentage of eggs deposited in redds that survive through incubation and emergence to capture.

Assumptions

- No distinction is made between deposition of unfertilized eggs and embryo or alevin mortality.

- Flow reductions and subsequent redd dewatering during the incubation period are assumed not to occur.

- There is no difference in survival from egg deposition through emergence between spring-run Chinook salmon and fall-run Chinook salmon.

- Because fall-run Chinook salmon emigrate shortly after emergence, juvenile ocean-type Chinook salmon in-river survival is assumed to be high. Therefore, In-River Survival Rates only were calculated for emigrating stream-type Chinook salmon.

- Predation is the most common cause of mortality among fry and fingerling Chinook salmon.

- Only a proportion of juveniles will be preyed upon.

- The proportion of juveniles preyed upon depends on juvenile Chinook salmon emigration timing, size at time of emigration, and the species and abundance of predators present at the time of migration.

- Water temperatures recommended by regulatory agencies, including NOAA Fisheries and DFG, protective of Chinook salmon spawning and egg incubation, and juvenile rearing and emigration will be provided in the Feather River tributaries to Lake Oroville (i.e., there will be no significant water temperature related mortality).

- The survival rates of migrating juveniles are influenced by river flows.

- Flow fluctuations during the juvenile Chinook salmon emigration period would be minimized.

- Flows recommended for protection of emigrating juvenile Chinook salmon will be provided during the juvenile Chinook salmon emigration period.

- The incidence of disease is dependent on water temperature.

- Mortality rates resulting from competition are independent of whether inter- or intraspecific competition occurs.

Biological Justification

Bradford (1995) collected published and unpublished literature on salmon egg survival and analyzed 40 cases in which at least 10 years of data was available. In most cases potential egg deposition versus the estimated number of fry emerging the following spring was examined to obtain estimates of egg to fry survival rates. The average salmon egg to fry emergence survival rate across all species examined was eight percent. However, it was reported that, on average, Coho salmon egg to fry emergence survival was greater than of chum salmon, pink salmon, or sockeye salmon. The average egg to fry emergence survival rate reported for pink salmon, chum salmon, and sockeye salmon was seven percent whereas the average Coho salmon egg to fry emergence survival rate was reported to be 19 percent (Bradford 1995). Estimates of Coho salmon egg to fry emergence survival rates were also calculated for Deer Creek, Needle Branch, and Flynn Creek where survival rates where reported to be 54.4%, 25.1% and 13.6%, respectively (Koski 1966). Koski (1966) reported that according to Wales and Coots (1955) egg to fry emergence survival for Fall creek Chinook salmon ranged from seven percent to 32% during a four year study period. In a study evaluating the effects of the Coffelt System 91 Electroanesthesia Unit on survival of egg to fry stages of Chinook salmon, it was reported that the average egg to fry mortality was 6.6 percent for progeny of electroshocked adults and 11.8 percent for progeny of control adults (Tipping and Gilhuly 1996). Therefore, the Chinook salmon egg to fry emergence survival rate was 88.2 percent for progeny of control adults and 93.4

percent for progeny of electroanesthetized adults. According to Bradford (1995) Chinook salmon egg to smolt survival rates should be higher than those for other pacific salmon species because Chinook salmon have a larger body size, which allows them to "*spawn in larger rivers, use larger gravels, and deposit their eggs deeper in the streambed, all of which may contribute to higher egg to fry survival* (Chapman 1988, Healey 1991, M. J. Bradford, unpublished data *in* Bradford (1995)."

An analysis of the egg to fry emergence survival rates reported for each species indicates that there is a great deal of variability between studies. Environmental factors such as incidence of floods, droughts and freezing (Wickett 1958 *in* Bradford (1995) as well as spawning habitat characteristics such as gravel quality and density of spawning adults (Chapman 1988 *in* Bradford (1995) were reported to affect the survival of salmon eggs and alevins. In addition, Koski (1966) reported that gravel composition, gravel permeability, dissolved oxygen and gravel stability also are associated with egg survival to emergence.

Although egg to fry emergence survival rates for Coho salmon, pink salmon, chum salmon, sockeye salmon, and Chinook salmon were examined, the reported Chinook salmon survival rates were chosen to represent the best case, expected, and worst case egg to fry emergence survival rates for the upper Feather River tributaries. Because the variability in reported egg to fry emergence survival estimates vary substantially between species, it was assumed that Chinook salmon egg to fry emergence rates reported from Fall Creek by Wales and Coots (1955) *in* Koski (1966) were more representative of Feather River Chinook salmon than other species. Egg to fry emergence survival rates obtained from Tipping and Gilhuly (1996) were not considered representative of Feather River Chinook salmon egg to fry emergence survival rates because the experiment produced substantially higher egg to fry emergence rates in an electroanesthetized experimental group than in the control group.

Predation reportedly is the principal cause of mortality among fry and fingerling Chinook salmon (Foerester and Ricker 1941 and Hunter 1959 *in* Healey (1991). Evanson et al. (1981) *in* Fresh (1997) reported that the average annual loss of wild Chinook salmon and steelhead over a three year period due to predation by hatchery fish was 9.7% in the Rogue River, Oregon. Martin et al. (1993) *in* Fresh (1997) reported that 95% of juvenile Chinook salmon were preyed upon in the Tucannon River, Washington within 4.5 months following a release of juvenile steelhead. Smallmouth bass within the Columbia River, Washington were reported to consume 1.4 (May 2-3) to1.0 (June 20-21) salmonids per predator daily. Northern pikeminnow were reported to consume from 0.55 (May 2-3) to 0.34 (June 20-21) salmonids per predator per day (Tabor et al. 1993). Northern pikeminnow reportedly consumed 21% to 35% of emigrating juvenile salmonids in 1992, 22% to 32% in 1994, and 9% to 20% in 1995 downstream from the Bonneville Dam on the Columbia River (Zimmerman and Ward 1999). Rogers et al. (1972) *in* Fresh (1997) reported that Artic char consumed 33% to 66% of outmigrating sockeye salmon smolts in one year in the Agulowak River, Alaska. In 1914, striped bass were introduced into the Coos River, Oregon and a predation model developed by Johnson et al. (1992) reportedly estimated that striped bass in this system would consume between 42,000 and 383,000 juvenile salmonids (Fresh 1997). In addition to fish predation on juvenile salmonids, studies on the Big Qualicum River, Vancouver Island reported avian predation rates on juvenile Chinook salmon ranging from 10.4% to 65% (Mace 1983 and Wood 1987 *in* Roby et al. (1997)). In the Columbia River system, Roby et al. (1997) estimated the number of PIT tagged smolts consumed by the Rice Island Caspian tern colony and found that mortality estimates for outmigrating juvenile salmonid smolts that reached the estuary were in the range of 6 percent to 25 percent in 1997.

Water temperature also is an important factor influencing survival and growth of juvenile salmonids (Moyle 2002). It has been reported that Sacramento River fall-run Chinook salmon mortality was lowest at water temperatures of 43.5°F to 57.5°F (6.4°C to 14.2°C), and exceeded 80% when water temperatures exceeded 61°F (16.1°C) (Healey 1977). A laboratory study that was conducted on the survival of rearing Sacramento River fall- and winter-run Chinook salmon reported that at water temperatures of 52°F to 54°F (11.1°C to 12.2°C), the mortality rate for rearing juvenile fall-run Chinook salmon was 23%. The mortality rate for rearing juvenile fall-run Chinook salmon at water temperature ranges of 56°F to 64°F (13.3°C to 17.8°C), ranged from 56% to 94% (USFWS 1999). Additionally, it was reported that at water temperature ranges of 56°F to 58°F (13.3°C to 14.4°C), the mortality rate for rearing juvenile winter-run Chinook salmon was 25%. The mortality rate for rearing juvenile winter-run Chinook salmon at water temperature ranges of 60°F to 62°F (15.6°C to 16.7°C) ranged from 45% to 81% (USFWS 1999). The mortality rate of rearing juvenile winter-run Chinook salmon was reported to be 18% at 56°F (13.3°C). At 50 °F (10°C) the mortality rate reported for rearing juvenile fall-run Chinook salmon was 16% (USFWS 1999). However, it is assumed that water temperatures protective of emigrating juvenile Chinook salmon would be provided during the emigration period. Therefore, water temperature induced mortality rates would be negligible.

In addition to predation and water temperature, flow also influences juvenile Chinook salmon survival rates. Survival estimates for Chinook salmon emigrating through the San Joaquin River system were calculated as part of the Vernalis Adaptive Management Plan (VAMP) during 2002. Emigrating juveniles were evaluated during emigration from Durham Ferry, Mossdale, and Jersey Point on the San Joaquin River to Antioch and Chipps Island in the Sacramento-San Joaquin Delta (Delta). During the evaluation, survival was estimated under two different flow regimes. After a 1,500 cfs increase in flow, the survival rate of juvenile Chinook salmon reportedly increased from 8% to 15% (San Joaquin River Group Authority 2002). It is assumed that adequate flows would be provided in the upper Feather River tributaries during the emigration period of juvenile Chinook salmon. Therefore, survival rates would not be adversely affected by flows in the upper Feather River tributaries.

Flow fluctuations reportedly could influence emigrating juvenile Chinook salmon survival rates when receding flows isolate fry from the main river channel (Bauersfeld 1978; DWR 2003; SWRI 2004). Fluctuating flows reportedly result in considerable stranding and loss of fall-run Chinook salmon juveniles in the lower American River. For example, on May 31, 1990, a flow reduction in the lower American River resulted in the stranding of several thousand juvenile Chinook salmon and steelhead in the vicinity of Fair Oaks below Nimbus Dam. The associated mortality rate for stranded juveniles during that flow reduction reportedly was near 100%. During stranding events, sources of mortality include acute thermal stress, and predation by fish and avian predators (SWRI 2004). Because flows adequate for juvenile Chinook salmon emigration would be provided during the emigration period of juvenile Chinook salmon, it is assumed that flow fluctuations would be minimized and not contribute substantially to juvenile Chinook salmon mortality rates in the upper Feather River tributaries.

Bacterial Kidney Disease (BKD) is a systemic infection affecting salmonids that is normally slowly progressive and frequently fatal (Banner et al. 1983 *in* Pacific Fishery Management Council (2003)). Because a primary function of fish kidneys is osmoregulation, a consequence of BKD infection, is a lack of ability of emigrating juvenile salmonids to acclimatize to seawater. The mortality rate of infected Coho salmon smolts reportedly was 17.2% in freshwater (Fryer and Sanders 1981 *in* Pacific Fishery Management Council (2003)). BKD reportedly can cause mortality in a wide range of water temperatures, however, the onset and magnitude of mortality is dependent on water temperature (Sanders, Pilcher and Fryer 1977 *in* Pacific Fishery Management Council (2003)). Because water temperatures protective of emigrating juvenile Chinook salmon would be provided, it is assumed that BKD infection rates would be minimized and associated mortality rates would be negligible.

Competition between non-native species and native salmonid species has been reportedly as one cause of anadromous salmonid population declines in the Columbia River system (Kaczynski and Palmisano 1992; Bevan et al. 1994 *in* Fresh (1997). In the Columbia River the abundance of American shad reportedly recently increased to the highest historic levels concurrently with declines to critical levels of salmon and steelhead (Fresh 1997). Competition between hatchery spawned and wild salmonids reportedly is often cited as a mechanism to explain how hatchery fish introductions have impacted native salmonids (Fresh 1997). Nickelson et al. (1986) *in* Fresh (1979) reported a 44% decline in the abundance of wild juvenile Coho salmon in Oregon coastal streams following the release of hatchery spawned juvenile Coho salmon (Fresh 1997). Nielsen (1994) *in* Fresh (1977) reported that agonistic encounters between hatchery and wild juvenile Coho salmon resulted in the displacement of 83% of the wild juveniles from their usual microhabitats in the Noyo River, California. Competition between non-native species and density dependant competition between juvenile Chinook salmon could potentially influence in-river survival rates of emigrating juvenile Chinook salmon.

In River Egg to Smolt Survival represents a broad period that was previously accounted for in the fish passage model separately by two model elements: 1) egg deposition to emergence survival, and 2) in river survival of post emergent fry. The change in approach to the analysis was necessary because little quantitative information for the period from emergence to the onset of downstream migration was available (most studies provide estimates for egg to fry/smolt survival). Factors including spawning gravel quantity, flood frequency, spawner density, predation, environmental stress, and disease outbreaks contribute to salmon mortality during the period of egg deposition to smolt downstream migration. Some estimates for ocean-type Chinook salmon egg to smolt survival are available from other modeling efforts on Central Valley salmon rivers. Jager and Rose (2003) developed a salmon mortality model for the Tuolumne River that predicted a maximum egg to smolt survival of approximately 20%. However, this estimate is of limited value because it is based on a series of model parameters that do not appear to have any empirical basis. A model developed for winter run Chinook salmon on the Sacramento River uses an estimate of roughly 15% as an egg to smolt survival rate (Cramer et al. 2003; pers. com. D. Odenweller, 2004). Bradford (1995) conducted a review of Pacific salmon survival data that summarized Chinook salmon egg to smolt survival rates in nine rivers over 66 collective sampling years for Chinook salmon exhibiting both ocean- and stream-type life history strategies. Another important feature in the literature review conducted by Bradford (1995) was that the reported egg to smolt survival rates were specific to the freshwater phase and did not include losses associated with migrations from natal areas to the marine environment. Data provided by Bradford (1995) indicated an average survival rate for juvenile Chinook salmon exhibiting an ocean-type life history of nine percent with a range from three percent to 12 percent. Collectively, the studies examined suggest appropriate values for In-River Egg to Smolt Survival would be 15 percent, nine percent, and three percent for best, expected, and worst case scenarios, respectively. The best case value is based on the winter run Chinook model, the expected case, and worse case values were derived from mean and minimum values reported by Bradford (1995).

3.0 JUVENILE COLLECTION

3.1 LOW TRIBUTARY FLOW – SCREEN

3.1.1 Proportion of Juvenile Capture

Definition of Terms

- The proportion of the emigrating juvenile Chinook salmon population captured by the tributary low flow fish screens is defined as the Proportion of Juvenile Capture.

Assumptions

- Low-flow fish screens are functional during periods of the year characterized by relatively low flows. An index flow of 1,220 cfs was defined as the flow above which the tributary low-flow fish screens would be unusable.
- Off-channel fish screens would be designed and constructed to be functional during 95 percent of all flows.
- Juvenile spring- and fall-run Chinook salmon emigration timing in the lower Feather River is similar to, and representative of, the potential emigration timing of juvenile Chinook salmon in the Lake Oroville tributaries. Juvenile Chinook salmon emigrate from mid-November through June.
- An equal percentage of the population of juvenile Chinook salmon emigrates each day during the emigration period.
- Rotary screw trap data is not biased by fish size.
- When in operation, screens capture 100 percent of emigrating juvenile Chinook salmon.

Biological Justification

Juvenile Chinook salmon emigration timing was determined from rotary screw trap data from the lower Feather River (DWR 2002; Seesholtz et al. 2003). The lower Feather River data suggested emigration timing for spring- and fall-run Chinook salmon, separately, based on juvenile outmigrant length-at-date from the Sacramento River Daily Length Table (Green 1992 *in* DWR (2002)). Because the length-at-date criteria used to determine the race of juvenile Chinook salmon captured may be somewhat inaccurate (DWR 2002) for the purposes of model development, no distinction was made between spring-run and fall-run Chinook salmon emigration periods. Additionally, for the purposes of model development, it was assumed that rotary screw trap data is not size-biased, and reflects true migration patterns of emigrating juvenile salmonids. Therefore, based on available data, it was determined that juvenile Chinook salmon in the lower Feather River emigrate from mid-November through June. Juvenile Chinook salmon emigration patterns in the lower Feather River are assumed to be representative of potential emigration patterns in the upper Feather River tributaries to Lake Oroville (i.e., there is no difference in emigration timing between upstream tributaries and the lower Feather River). Additionally, because flows, predator and prey distribution, and other environmental variables in the upper Feather River tributaries potentially differ from those of the lower Feather River, and because the temporal distribution of emigrating juvenile Chinook salmon during the emigration period was based on low sample sizes, for purposes of model development, it was assumed that the distribution of emigrating juveniles was equal during the defined emigration period (i.e., an equal percentage of the population emigrated each day).

The index flow chosen on which to perform the analysis of the proportion of time that a low-flow screen would be utilizable was 1,220 cfs. In a study conducted by the U.S. Army Corps of Engineers (USACE) (2000), low flow v-screens were proposed for use at the Cougar Lake project in Oregon. The U.S. Army Corps of Engineers reported that the low flow v-screens, designed for use in the South Fork McKenzie River, were designed to pass 1,220 cfs through the screen system (USACE 2000). Because river channel morphology determines the water velocity in a river at a given flow, the screen design was assumed to be site-specific. However, a lack of site-specific information in the upper Feather River tributaries to Lake Oroville precluded definitive selection of a flow at which a low-flow screen would be utilizable. Therefore, an assumption was made that 1,220 cfs would be an appropriate index value for use in this modeling exercise.

Flow records obtained from the California Data Exchange Center (CDEC) were examined to characterize the flows in the tributaries to Lake Oroville (California Data Exchange Center Website). The reported values of mean daily flows at stations on the West Branch of the North Fork Feather River (West Branch), Middle Fork Feather River (Middle Fork), and North Fork Feather River (North Fork) were recorded and analyzed for the feasibility of placing low-flow fish screens at the locations of the flow gages. The stations for which flow data were available included the West Branch at Paradise, the West Branch at Yankee Hill, Middle Fork at Merrimac, North Fork at Pulga, and the North Fork below Pulga and Poe Dam (North Fork Poe and Pulga combined).

Data collected at an additional gage station located on the North Fork below Poe Dam also was examined. Detailed analysis of the data indicated that the gage could potentially be unreliable at some flows, however. Therefore, because documentation of the reliability of the data collected from the gage station located below Poe Dam was unavailable, only two gage stations (North Fork at Pulga and North Fork Poe and Pulga combined) were analyzed for to determine the Proportion of Juvenile Capture in the North Fork.

Historic daily mean flow data were available for each of the flow stations from CDEC (California Data Exchange Center Website). Daily mean flow data were averaged for each available year during the period of record to obtain a single data set representative of all years for each gage station. Obtaining an average of all available data shows the average seasonal variability in flow and the average proportion of time at which the screening devices would function using an index value of 1,220 cfs as the criterion determining functionality. However, the average of all available daily mean flows likely does not reflect the variance in mean daily flow that most likely occurs.

Two streamflow station gauges are located on the West Branch. The gage station near Paradise has a period of record extending from 1957 through 1986 containing a total of 10,592 data points. The second gage station is the West Branch Feather River near Yankee Hill. The period of record for the West Branch Gage Station near Yankee Hill extended from 1930 through 1963, and contained 12,053 data points (California Data Exchange Center Website).

The Middle Fork Feather River had one gage station at Merrimac, which had a period of record that extended from 1951 through 1986 and contained 12,784 data points (California Data Exchange Center Website).

Two gage stations are located on the North Fork. The period of record at the gage station labeled North Fork Feather River at Pulga extended from 1911 through 2002 and contained over 33,000 data points. The gage station on the North Fork Feather River below both Pulga and Poe Dam recorded the highest flows in the North Fork. The period of record at the gage station named North Fork Feather River, Pulga and Poe extended from 1967 through 1983 and contained 5,844 data points (California Data Exchange Center Website).

In order to assess the functionality of the screens at each station, exceedance curves for each flow station were created using 1,220 cfs as an index value. Mean daily flow data for each gage station was averaged over the period of record to determine the average flow for each individual day. Mean daily flows were plotted along with the index value (1, 220 cfs) to determine the percentage of time that low-flow fish screens would be utilizable at each gage station. The percentages expressed in Table A3-1 are the percentage of time that the flow at each of the locations was below the index value flow of 1,220 cfs. Figures A3-1 through A3-5 show mean daily flows over the period of record at each of the gage stations plotted with the index value of 1,220 cfs.

Both gage stations located in the West Branch had a small proportion of flows above 1, 220 cfs over the period of record. Streamflow data for the period of record at the gage station at Paradise shows that average flows remained below the index flow for approximately 99.6 percent of the Chinook salmon juvenile emigration period. Mean daily flows recorded at the gage station at Yankee Hill did not exceed the index flow at any time during the period of record.

Table A3-1 Percentage of time that index flow was not exceeded at each flow gauge station within the existing period of record for that station.

Station name	Period of record	Number of days the average flows were below the index flow during Chinook salmon juvenile emigration period (229 days)	Percentage of time average flows were below the index flow (1,220 cfs)
West Branch Feather River at Paradise	1951-1986	228 days	99.56%
West Branch Feather River at Yankee Hill	1930-1963	229 days	100.0%
Middle Fork Feather River at Merrimac	1951-1986	53 days	23.25%
North Fork Feather River at Pulga	1911-2002	114 days	49.78%
North Fork Feather River Pulga and Poe combined	1967-1983	0 days	0.0%

Average mean daily flows for the gage station on the Middle Fork at Yankee Hill were below the index flow for 53 days during the period of record, which represented approximately 23.3 percent of the time.

Average flows below 1,220 cfs were recorded at one of the two gage stations on the North Fork Feather River. Average flows recorded at the station at Pulga indicate that flows at Pulga remain below 1,220 cfs approximately 50 percent of the time. Average flows below 1, 220 cfs for the period of record at the station below Pulga and Poe do not occur.

It is important to note that average flows are not necessarily representative of the actually flows recorded at these stations. Because reported flows were averaged to calculate mean daily flow, and the mean daily flows during the period of record were averaged to obtain the flow utilized in the analyses, fluctuations that may have occurred within the course of a day or between days may not be reported in the analysis. Therefore, it is necessary to examine daily flows for individual years at each station to determine the range of flows a fish screen would be required to accommodate in order to operate for a given percentage of time.

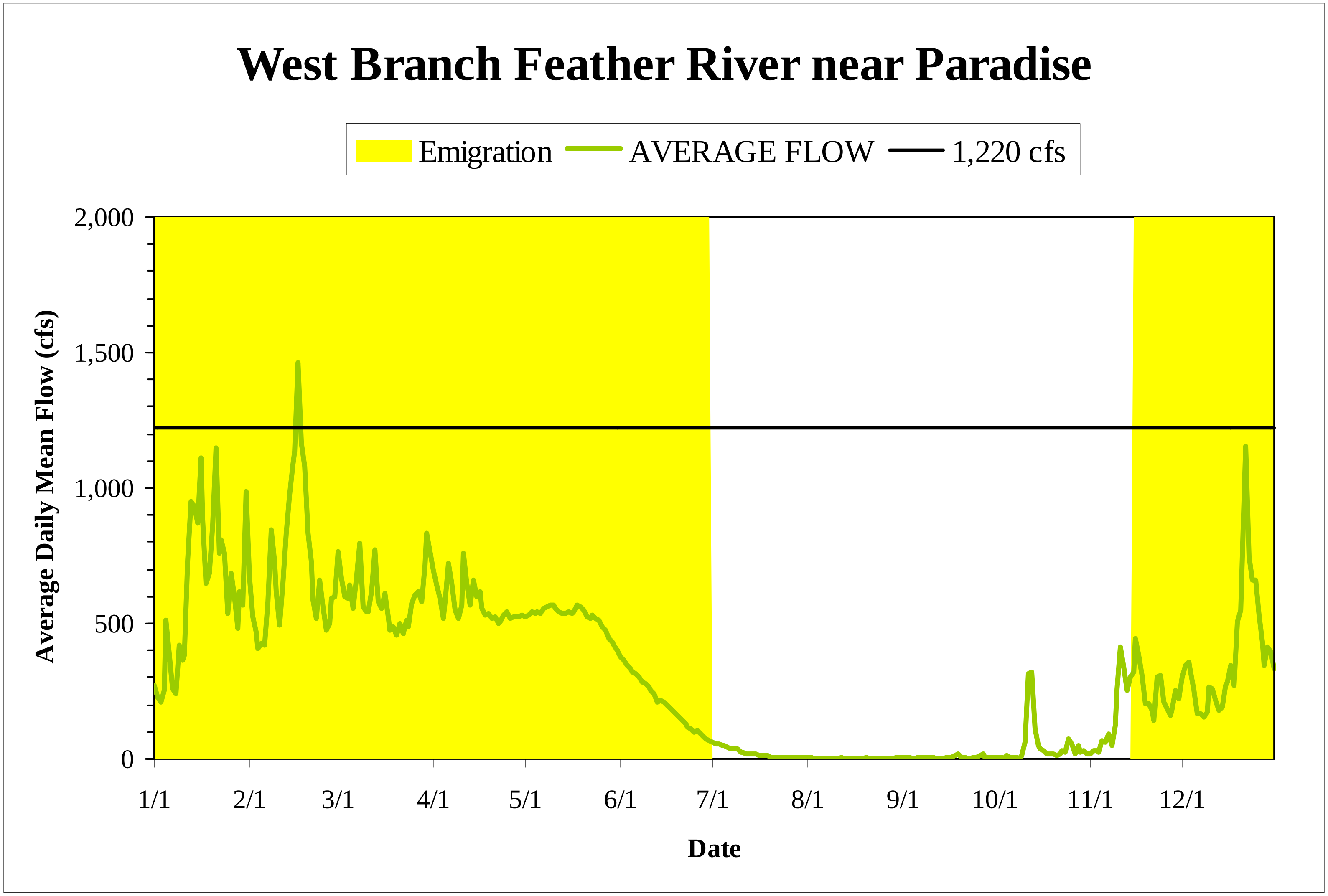

Figure A3-1. Average daily flow in the West Branch Feather River near Paradise from 1951 through 1986. Shaded areas indicate the Chinook salmon emigration period. The horizontal line indicates the index flow of 1,220 cfs at which low flow screens were assumed to be useable.

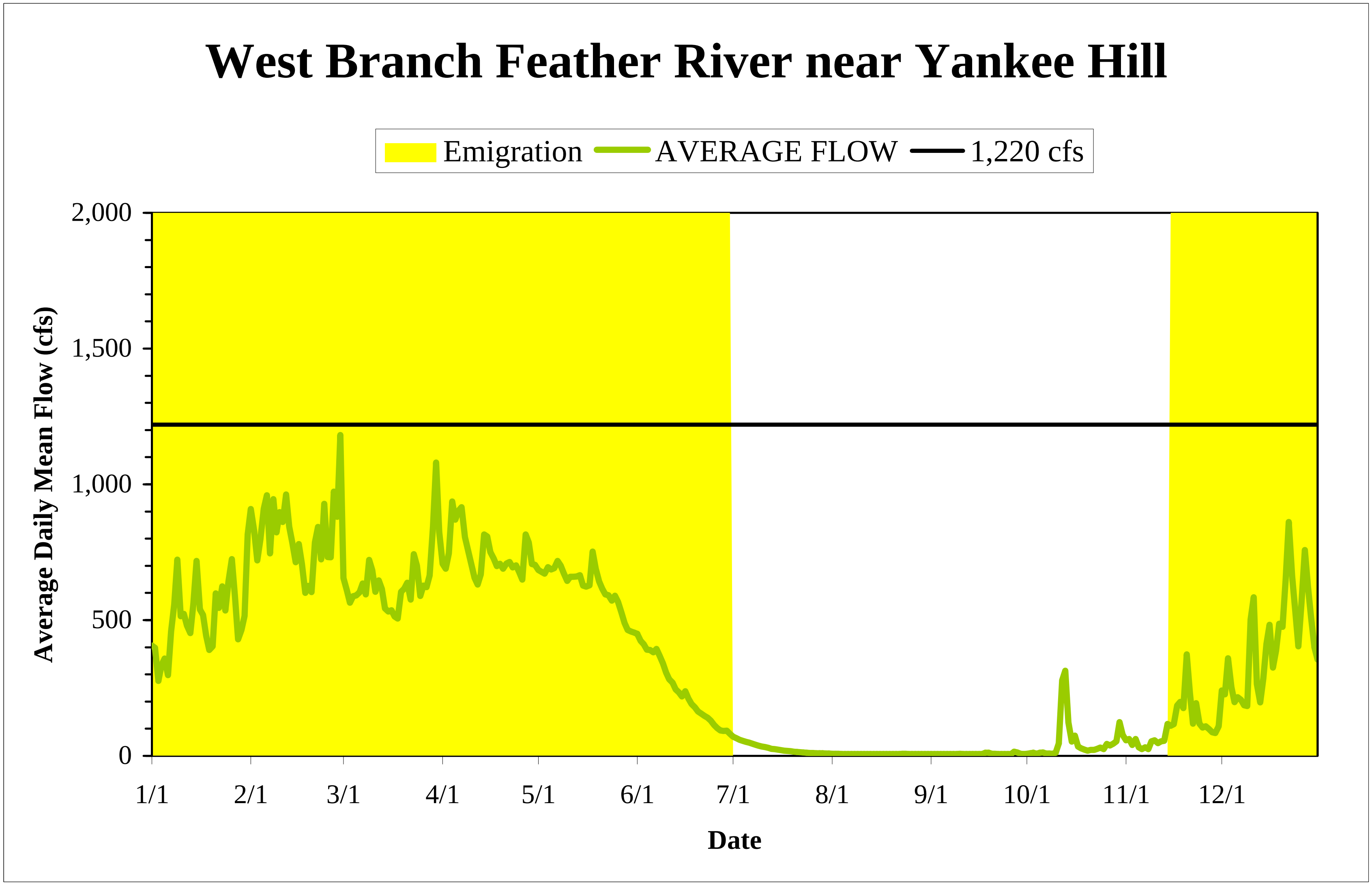

Figure A3-2. Average daily flow in the West Branch Feather River near Yankee Hill from 1930 through 1963. Shaded areas indicate the Chinook salmon emigration period. The horizontal line indicates the index flow of 1,220 cfs at which low flow screens were assumed to be usable.

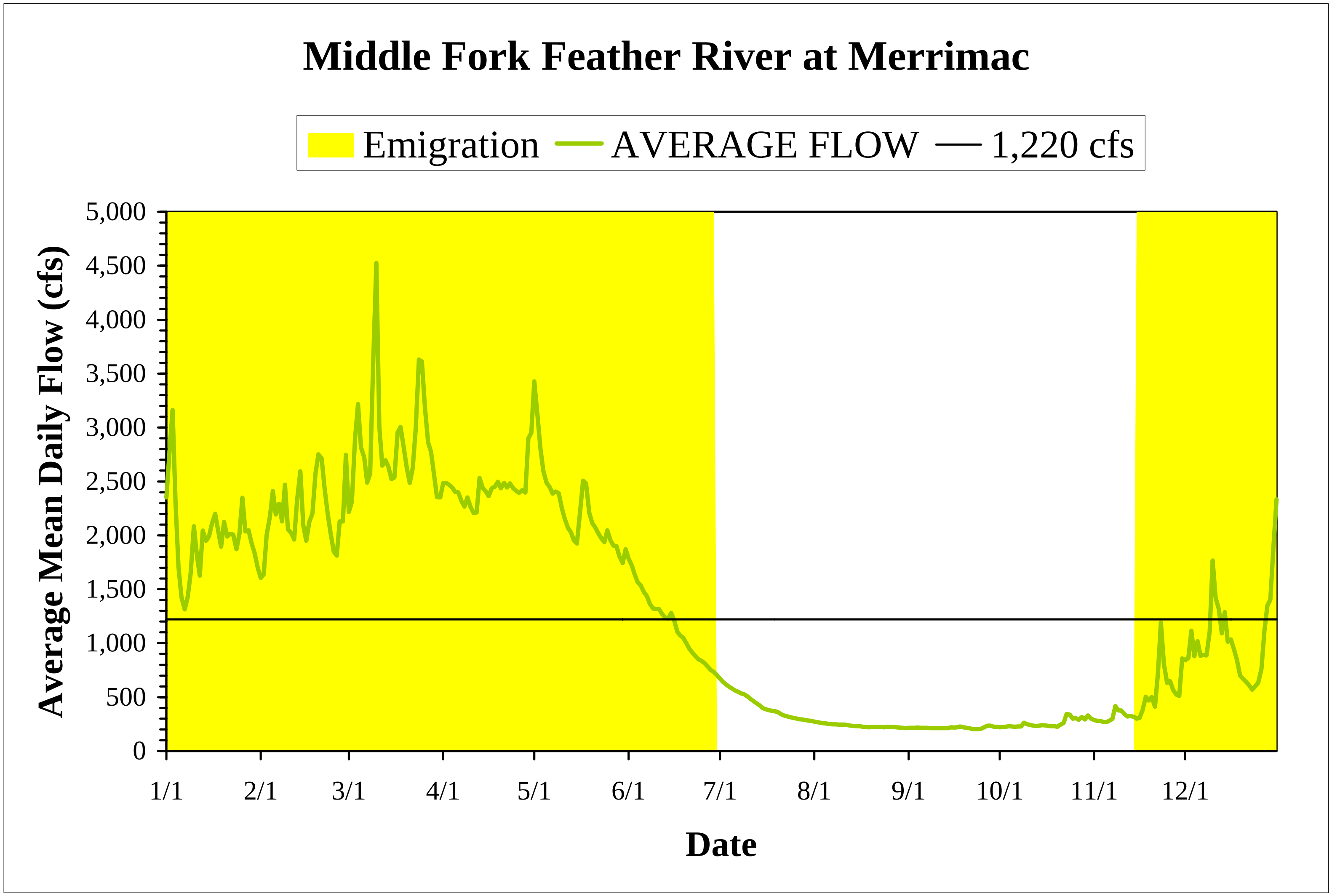

Figure A3-3. Average daily flow in the Middle Fork Feather River at Merrimac from 1951 through 1986. Shaded areas indicate the Chinook salmon emigration period. The horizontal line indicates the index flow of 1,220 cfs at which low flow screens were assumed to be usable.

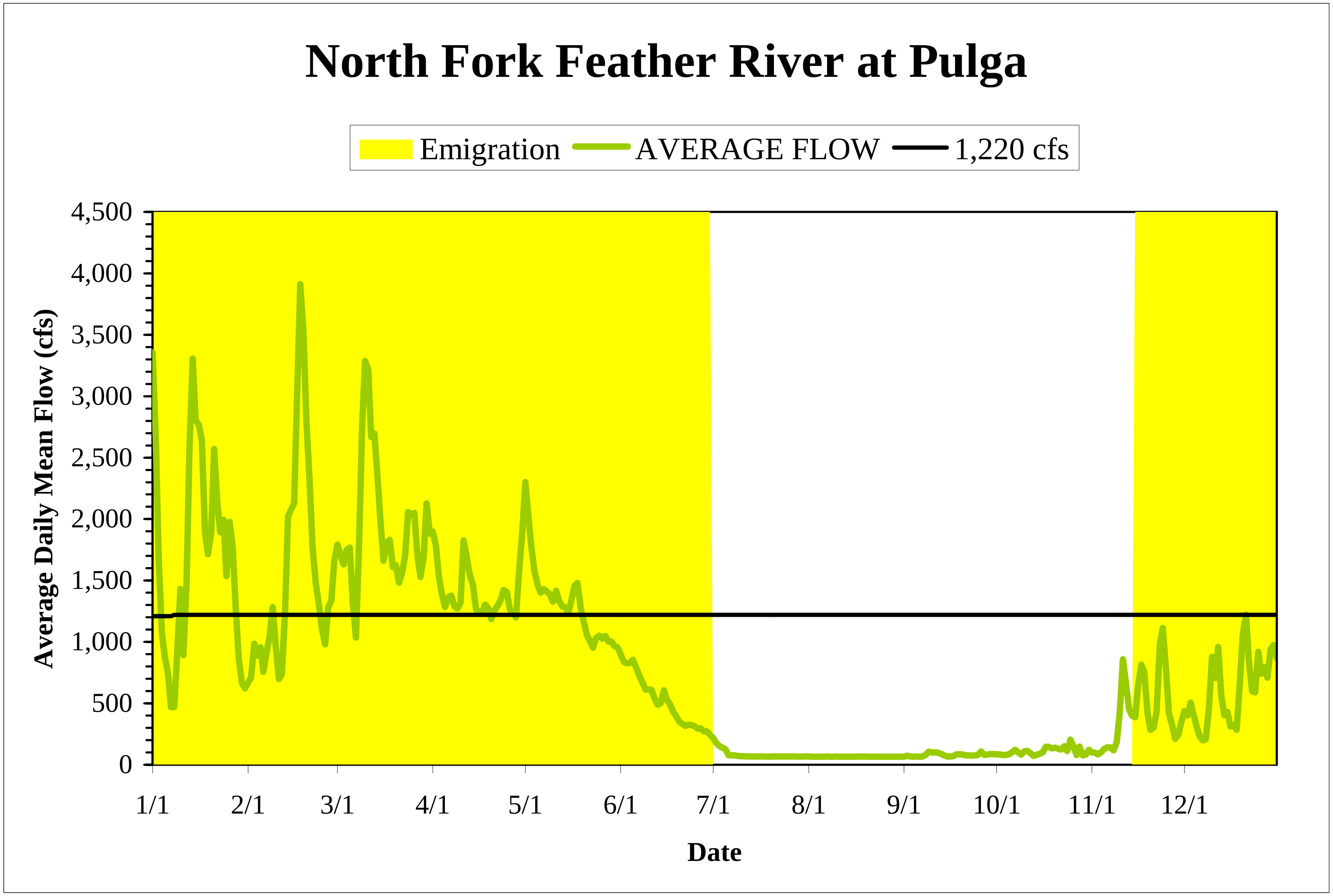

Figure A3-4. Average daily flow in the North Fork Feather River at Pulga from 1911 through 2002. Shaded areas indicate the Chinook salmon emigration period. The horizontal line indicates the index flow of 1,220 cfs at which low flow screens were assumed to be usable.

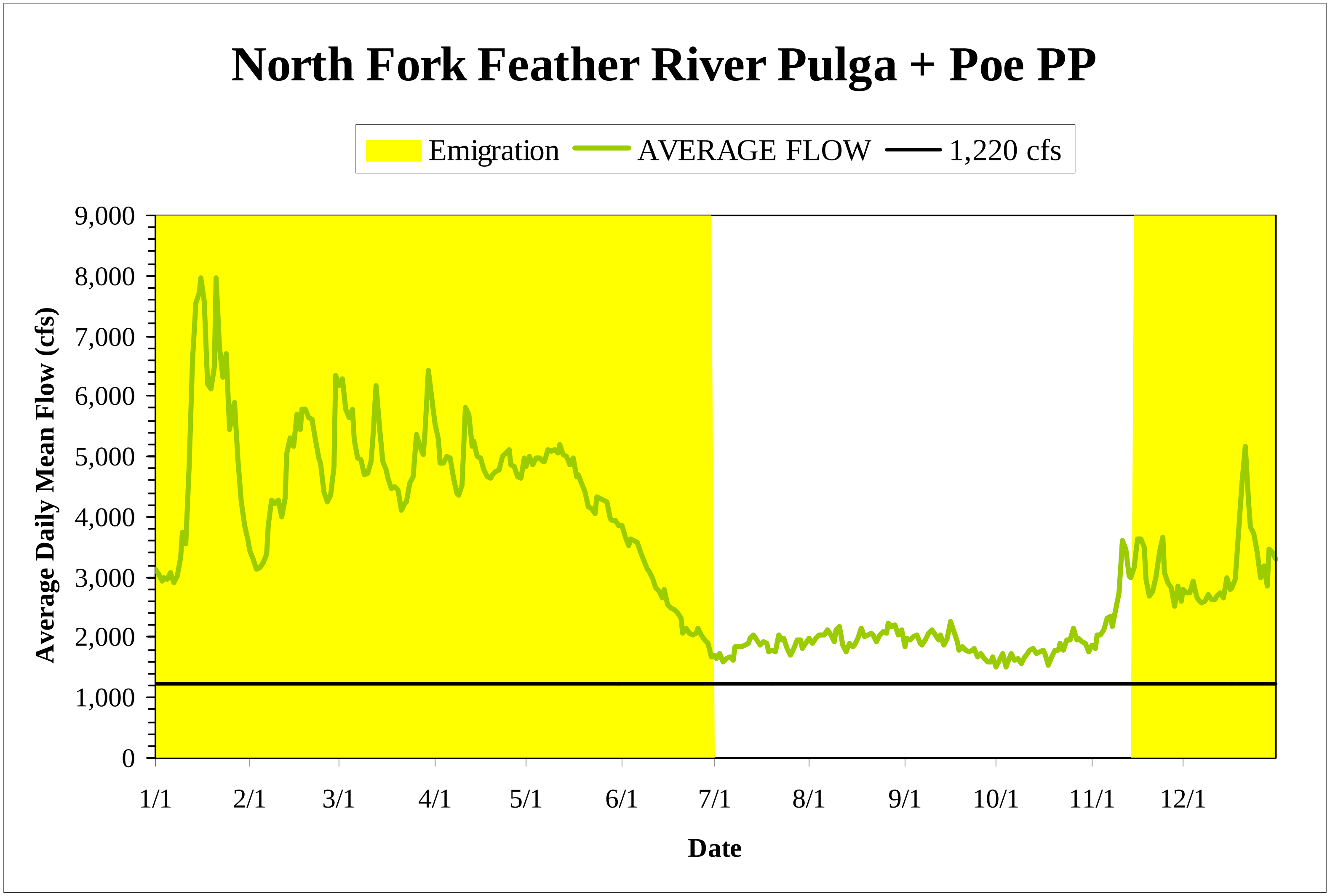

Figure A3-5. Average daily flow in the North Fork Feather River Pulga and Poe PP Combined from 1967 through 1983. Shaded areas indicate the Chinook salmon emigration period. The horizontal line indicates the index flow of 1,220 cfs at which low flow screens were assumed to be usable.

NOAA Fisheries (1997) established draft fish screening efficiency criteria in "Fish Screening Criteria for Anadromous Salmonids" (NOAA Fisheries 1997). The criterion for juvenile fish screen efficiency was preliminarily mandated by NOAA Fisheries to be 95 percent. If it is assumed that fish screens are one hundred percent efficient, and are operated during the peak 95 percent of all flows encountered during the defined juvenile Chinook salmon emigration period, and if it is assumed that an equal percentage of the population of juvenile Chinook salmon emigrate each day during the defined emigration period, fish screens would conform to NOAA Fisheries' juvenile screening criteria. It is assumed that an off-channel diversion facility would need to be constructed to accommodate 95 percent of all flows encountered during the juvenile Chinook salmon emigration period.

If the screens are 95 percent efficient (100 percent efficient during operation for 95 percent of all flows encountered during the juvenile Chinook salmon emigration period), then the flows at which this efficiency could be achieved can be calculated from the mean daily streamflow data recorded at each gage station during the period of record. The flow below which 95 percent of all mean daily flows occurred for each gage station is presented in Table A3-2.

Due to screen design considerations, it is uncertain whether screen efficiency could potentially be higher than 95 percent. Screening devices may be removed or become non-functional during periods when flows are above the threshold established under which the screens would be designed to operate. However, it also is possible that they may remain in place and be functional, yet capture a smaller proportion of emigrating juvenile Chinook salmon.

Table A3-2. Flow (cfs) required to achieve functionality 95 percent of the Chinook salmon juvenile emigration period at designated flow gauge stations.

Station name	Flow (cfs)
West Branch Feather River at Paradise	1,590 cfs
West Branch Feather River at Yankee Hill	1,720 cfs
Middle Fork Feather River at Merrimac	5,734 cfs
North Fork Feather River at Pulga	6,070 cfs
North Fork Feather River Pulga and Poe combined	10,400 cfs

For a screening device to be functional at the West Branch Feather River at Paradise flow gauge station during 95 percent of the juvenile Chinook salmon emigration period, a device capable of screening 1,590 cfs would be required. A device designed to operate during 95 percent of juvenile Chinook salmon emigration period at the Yankee Hill station on the West Branch would be required to accommodate flows of 1,720 cfs.

The Middle Fork Feather River at Merrimac station would require a device designed to accommodate flows up to 5,734 cfs in order to be functional at 95 percent of flows during the Chinook salmon emigration period.

Screening devices operating at the Pulga streamflow gauge station on the North Fork Feather River would be required to be functional at flows of 6,070 cfs in order to operate for 95 percent of the juvenile Chinook salmon emigration period. Based on the mean daily flows observed at the gage station below Pulga and Poe, a screening device located at this station would be required to be utilizable at flows up to 10,400 cfs in order to operate during 95 percent of the juvenile Chinook salmon emigration period.

3.1.2 Screen Capture Efficiency

Definition of Terms

- For the purposes of model development, Screen Capture Efficiency is defined as the proportion of emigrating juvenile Chinook salmon captured and passed beyond the screen. Screen Capture Efficiency includes, but is not limited to, the proportion of emigrating juveniles captured by the screen, and the proportion of juveniles surviving capture.

Assumptions

- In-river flows are optimal for maximum Screen Capture Efficiency.

- In-river conditions are optimal for maximum survival of juvenile Chinook salmon captured and passed (i.e. water temperatures provided are below those that cause stress in juvenile Chinook salmon).

Biological Justification

After emergence, juvenile Chinook salmon emigrate or rear in the river for several days to several months (Moyle 2002). During emigration, juveniles hatched upstream from a passage barrier would be required to pass below the barrier in order to complete their life cycles. One method of capturing juveniles for passage below Oroville Dam would be the use of instream screens.

Although screens are utilized in anadromous salmonid passage programs at various facilities, little information exists regarding exclusion barrier Screen Capture Efficiency. Efficiency rates have been reported for submersible traveling screens (STS) preventing juvenile salmonids from entering turbines at the Bonneville Second Powerhouse on the Columbia River (Gessel et al. 1991), although STS use differs substantially from the collection screens proposed for use in the upper Feather River tributaries. Therefore, criteria developed by NOAA Fisheries for fish screen use in the Klamath Hydroelectric Project were examined (pers. com. D. White, 2003). According to NOAA Fisheries (2003), juvenile survival through fish screens should meet or exceed 95%.

Because NOAA Fisheries developed the fish screen criteria for juvenile salmonid passage, it was assumed that the minimum fish screen efficiency recommended for the Klamath Hydroelectric Project would suffice as the worst case Screen Capture Efficiency for the upper Feather River Tributaries. Additionally, because screens would only capture emigrating juvenile Chinook salmon during relatively low flow (July through November) periods, it is assumed that the proportion of emigrating juvenile Chinook salmon captured by the screens is equal to the proportion of juveniles that encounter the screens. That is, all juveniles not subjected to in-river mortality are captured by the screens when they are in place and operating correctly. Also, during relatively high flow periods, screens would not be used and all emigrating juveniles would be captured by the downstream gulper system in the reservoir arms.

Although NOAA Fisheries (2003) criteria suggest fish screen capture efficiency meeting or exceeding 95%, it is assumed that 100% efficiency would not be obtained. Therefore, it is expected that actual fish screen efficiency would range between 95% and 99%. Therefore, for modeling purposes, Screen Capture Efficiency values of 99%, 97%, and 95% were estimated to be the best case, expected, and worst case scenarios, respectively.

3.2 HIGH TRIBUTARY FLOW - GULPER

3.2.1 In-reservoir Survival Rate

Definition of Terms

- In-Reservoir Survival Rate is the percentage of emigrating juvenile salmon that survive from reservoir entrance until capture at the gulper. Factors influencing juvenile Chinook salmon survival rates include, but are not limited to, predation, water temperature, flow, disease, and density dependent variables such as competition.

- In-Reservoir Survival Rate is the complement of in river mortality rate.

Assumptions

- Predation is the most common cause of mortality among fry and fingerling Chinook salmon in reservoirs.

- Only a proportion of juveniles entering the reservoir will be preyed upon.

- The proportion of juveniles preyed upon depends on emigration timing, the size of emigrating juveniles, and the species and density of predators present at the time of migration.

- Water temperatures recommended by regulatory agencies, including NOAA Fisheries and DFG, protective of Chinook salmon during juvenile rearing and emigration will be provided in the Feather River tributaries to Lake Oroville.
- Flow fluctuations during the juvenile emigration period will be minimized.
- The incidence of disease is dependent on water temperatures.
- Mortality rates associated with competition are independent of whether inter- or intraspecific competition occurs.
- For modeling purposes, residualization is considered equal to mortality.

Biological Justification

Most studies on predation of juvenile anadromous salmonids have focused on predation associated with dam passage facilities, particularly in the Columbia River system. These studies focus on predation associated with unusually high concentrations of out-migrating salmonids at passage facilities, or predation associated with injury or disorientation following dam passage. Reportedly significant salmonid mortality occurs within reservoirs primarily due to predation from piscivorous fish and birds, water temperature changes, residualization, and disease. It also has been reported that predators commonly cause the greatest mortality among fry and fingerling Chinook salmon and, in some cases, predation has been reported to be responsible for heavy losses (Foerster and Ricker 1941 and Hunter 1959 *in* Healey (1991).

Although a majority of the literature reviewed regarding in-reservoir predation focuses on predation by piscivorous fish, current research suggests that avian predation may also be an important source of juvenile salmonid mortality (Roby et al. 1997). The reported high juvenile salmonid mortality rates (low survival rates) in reservoirs is often attributed to dams, which can cause emigrating juvenile salmonids to become disoriented, delay juvenile salmonid emigration, and expose emigrating juveniles to high water temperatures. In addition to causing direct mortality, disorientation, delayed emigration, and exposure to high water temperatures increase the susceptibility of emigrating juvenile salmonids to predators (Rieman et al (1991), Beamesderfer and Rieman (1991), and Vigg et al. 1991 *in* Poe et al. (1991).

To quantify the effect of predation by fish on emigrating juvenile salmonids a literature review was conducted to determine predator gut contents (Poe et al. 1991), prey consumption rates (Vigg et al. 1991), and abundance of predators in reservoirs through which emigrating salmonids, including yearling Chinook salmon, subyearling Chinook salmon, juvenile Coho salmon, juvenile sockeye salmon, and juvenile steelhead migrate (Rieman et al. 1991). In studies conducted in the John Day Reservoir, a run-of-the-river reservoir on the Columbia River on the Washington-Oregon border, from 1983 through 1986, four main predator species, northern pikeminnow, walleye, smallmouth bass, and channel catfish, were identified during the period from April through August, the reported salmonid emigration period at the John Day Dam (Poe et al. 1991). The reservoir is approximately 75 miles long. Stomach content samples also were used to estimate the relative proportions of salmon and steelhead consumed by each predator (Rieman et al. 1991).

The average density of predators was reported to be 85,000 northern pikeminnow, 10,000 walleye, and 35,000 smallmouth bass. Channel catfish population estimates were not available. Approximately 18 million salmon and 1.3 million steelhead were estimated to have entered the John Day Reservoir in each migration season during the study period (April through August 1983 through 1986). The evaluation revealed a mean seasonal loss of 2.7 million juvenile salmon and steelhead resulting in an estimated loss of 14 percent with confidence limits ranging from 9 to 19 percent. Juvenile salmon were reported to be the most consumed prey species in all months (Rieman et al. 1991). However, no estimates of transit times were provided.

Another study by Normandeau Associates Inc. (2001) examined predation associated with the Williamette Falls Project on the Williamette River, Oregon. The study focused on predation associated with facility passage, in particular; survival in the tailrace following dam passage. Therefore, the applicability of the study to the Oroville Facilities Relicensing efforts is limited. Normandeau Associates Inc. (2001) reports predation for a single event, or more specifically, a one-day predation rate. A survival rate of 98 percent (2 percent mortality) was reported per day following passage through an artificial structure (Normandeau Associates Inc. 2001).

According to Roby et al. (1997), a substantial source of mortality to juvenile salmonids can be attributed to avian predators. In the Columbia River system, estimates of the number of PIT tagged smolts consumed by the Rice Island Caspian tern colony ranged from 6% to 25% in 1997 (Roby et al. 1997). Because Caspian terns are colonial nesters and because they are not common in the upper Feather River watershed, it is inappropriate to use juvenile salmonid predation rates associated with such colonial species. Little information was available on predation rates associated with other avian predators of juvenile Chinook salmon. It was assumed that avian predation on emigrating juvenile Chinook salmon would occur in a potential fish passage program. Because limited information was available however, avian predation was assumed to be negligible for purposes of modeling in-reservoir survival rates.

For the purposes of modeling, residualization of emigrating juvenile Chinook salmon would also be considered part of the in-reservoir mortality rate. A PIT tag study conducted at the lower Snake River Reservoir reported that between 1.7 and 2.0 percent of Fall-run Chinook salmon residualized in the Snake and Columbia River reservoirs (Downing and Prentice 2003). For modeling purposes, residualization rates are considered part of the in-reservoir mortality rate.

Little information was available in reviewed literature on the effects of high water temperatures, disease, and residualization on in-reservoir mortality rates of juvenile Chinook salmon. Because it is reported that water temperature is a limiting factor in juvenile Chinook salmon survival (Moyle 2002), it is assumed that water temperatures protective of emigrating juvenile Chinook salmon would be provided, and therefore water temperature related mortality would be minimized.

Disease also is a potential source of juvenile salmonid in-reservoir mortality. However, it is assumed that in-reservoir residence time will be between one and five days, depending on the location of the gulper. Therefore, disease related mortality in the reservoir would be minimal. Additionally, latent mortality associated with disease contracted in the upstream tributaries is considered as in-river mortality downstream from release.

Calculation of In-Reservoir Survival Rates was performed by combining both piscine predation and residualization rates. It is assumed that in-reservoir transit times would range from one to five days depending upon gulper location and differences in migratory behavior due to tributary flows, water temperature regimes, and gulper attraction flows. In order to calculate the best-case in-reservoir survival rate a one-day in-reservoir transit time was assumed and used to calculate the mortality rate associated with piscine predation. Because daily mortality rates in the Williamette River, Oregon were reported by (Normandeau Associates Inc. 2001) to be 2 percent per day, juvenile Chinook salmon emigrating through Lake Oroville for one day would be assumed to be exposed to 2 percent mortality. In addition, approximately 2 percent of emigrating juvenile Chinook salmon would be expected to residualize and remain in the reservoir. Adding the piscine predation rate associated with a one-day transit time to the residualization rate yields the best-case in-reservoir survival rate. Therefore, the best-case in-reservoir survival rate would be 96 percent. The worst-case in-reservoir survival rate could be calculated by using the same method as the best-case in-reservoir survival rate for an assumed five-day transit time. Utilizing piscine predation rates and residualization rates would yield a worst-case in-reservoir survival rate of approximately 82 percent. Alternatively, the worst-case in-reservoir survival rate could be derived from the in-reservoir predation study by Rieman et al. (1991). If the in-reservoir predation rate reported by Reiman et al. was utilized, the worst-case in-reservoir survival rate would be 86 percent (100%-14%=86%). Because the study conducted by Reiman et al. utilized actual in-reservoir predation rates rather than tailrace predation rates, 86 percent was chosen as the worst-case in reservoir survival rate. An expected survival rate of 91 percent was selected for modeling purposes because it is the mean survival rate between the best and worst-case scenarios. Therefore, the best case, expected, and worst case In-reservoir Survival Rate would be 96%, 91%, and 88%, respectively.

3.2.2 Gulper Capture Efficiency

Definition of Terms

- For the purposes of model development, Gulper Capture Efficiency is defined as the proportion of emigrating juvenile Chinook salmon captured and passed to an adjacent sorting mechanism. Gulper Capture Efficiency includes, but is not limited to, the proportion of emigrating juveniles captured by the gulper, and the proportion of juveniles surviving capture.

Assumptions

- All emigrating juvenile Chinook salmon not collected at the instream low velocity screens and not subjected to in-river mortality would be subject to capture at the gulpers.

- Water temperatures recommended by regulatory agencies, including NOAA Fisheries and DFG, protective of Chinook salmon during juvenile rearing and emigration will be provided in the Feather River tributaries to Lake Oroville.

- The gulpers would be positioned in the reservoir arms in locations where velocities through associated guide nets would not exceed 0.1 fps.

Biological Justification

After emergence, juvenile Chinook salmon emigrate or rear in the river for several days to several months (Moyle 2002). During emigration, juveniles hatched upstream from a passage barrier would be required to pass below the barrier in order to complete their life cycles. During higher flows (i.e. above 1,170 cfs), when screens are ineffective at capturing emigrating juvenile salmonids, gulper systems can be utilized (Puget Sound Energy Unpublished Work).

During a study conducted at the Upper Baker Lake fish gulper in 2002, acoustic tags were used to track the behavior of Coho and Sockeye salmon as they moved through the forebay of the reservoir toward the gulper. Analysis of the results revealed that large amounts of fish reportedly crossed the mouth of the surface collector mechanism utilized with the gulper, but did not enter the collection barge. Reportedly, 21 percent of the tagged juvenile Coho and Sockeye salmon were collected by the gulper (Puget Sound Energy Unpublished Work). Earlier studies at the Upper Baker Lake gulper from 1988 to 1992, used fixed location hydroacoustics to determine guidance effectiveness (FERC 1993). FERC (1993) reported that guidance efficiencies over the test period ranged from 67 percent to 79 percent. Survival associated with fish gulpers is assumed to be high, but limited information is available regarding injury related to the use of gulpers to guide and capture fish.

Because limited information on gulper devices is available, the Upper Baker Lake Gulper studies were utilized to determine best case, expected, and worst case gulper efficiencies in the arms of Lake Oroville. Additionally, because gulper devices require narrow inflow ranges in which to operate, it is assumed that the position of the gulper in Lake Oroville would provide similar conditions to those in Upper Baker Lake.

Because the two studies reported a range of efficiencies, the highest and lowest efficiency in either of the studies was chosen to represent the best and worst cases, respectively, for the Lake Oroville gulper. The mean of the highest and lowest reported efficiencies was chosen to represent the expected efficiency of the Lake Oroville gulper. Therefore the best case, expected, and worst case Gulper Capture Efficiency rates were estimated to be 79%, 50%, and 21%, respectively.

4.0 JUVENILE FISH SORTING

4.1. SORTING FACILITY

4.1.1 Sorting Efficiency

Definition of Terms

- For the purposes of model development, Sorting Efficiency is defined as the proportion of captured emigrating juvenile Chinook salmon successfully identified by species that survive the sorting procedure. Sorting consists of, but is not limited to, the use of sorting devices, physical handling by technicians while separating fish by species, or separating to PIT-tagged from untagged individuals. Devices considered for implementation in a potential Oroville Passage Program include removable mesh separators and bar sorters.

- Removable mesh separators and bar sorters are devices placed in each holding raceway or pool that separates larger fish from emigrating juvenile Chinook salmon.

Assumptions

- Personnel are equally trained and utilize standard operating procedures to readily differentiate between juvenile Chinook salmon and other fish found in the Feather River including other anadromous salmonid species and resident rainbow trout.

- Sorting Efficiency is independent of the sorting device used.

- Sorting occurs first by size, then by species.

- Mortality rates are equal between collection, sorting, and transport.

Biological Justification

Maintaining high levels of Sorting Efficiency involves sorting fish by size and by species, and maximizing survival rates (i.e. minimizing mortality rates) to emigrating juvenile Chinook salmon. Generally, sorting would be considered a two-step process. The first step would involve removing large fish, including adult salmonids and other adult fish, from emigrating juvenile Chinook salmon. The second step would be to sort fish by species. Sorting fish by size would occur using size exclusion devices, while sorting fish by species would be performed by trained technicians.

During the process of sorting captured fish by size, overall sorting efficiency could be decreased by device-induced mortality or the inability of sorting devices to separate emigrating juvenile Chinook salmon from larger fish captured. Because removal of juvenile salmonids from larger fish is simply a function of aperture size in either the removable mesh separator or the bar sorter, it is assumed that the ability of either device to sort fish by size is similar and that the efficiency associated with this portion of the process is high.

Additionally, overall Sorting Efficiency is dependant on technician ability to sort fish by species. Review of available literature revealed no information on devices capable of sorting individuals of similar size by species. Therefore, sorting by species would be performed by hand. It is assumed that experienced technicians are readily able to identify all species likely to be encountered during sorting in the upper Feather River including all salmonid and non-salmonid species. Based on current and historical stocking programs, salmonid species that could potentially be encountered include Chinook salmon, steelhead, Coho salmon, and resident rainbow trout. Because technicians would follow standard operating procedures and because quality control procedures would be in place at all sorting facilities, it is likely that sorting efficiency would not decrease substantially due to human errors during species identification.

During sorting, mortality related to stress and handling could occur. However, review of available literature revealed little information related to sorting induced mortality. According to Ward et al. (1997), estimates of 10%, 15%, and 20% mortality related to collection, handling, and transport of fish is consistent with a variety of literature sources. Based on the literature reviewed by Ward et al. (1997), an average of 15% mortality related to capture, sorting, and transport was assumed. Additionally, because sorting mortality was not reported separately, it was assumed that collection, handling, and sorting each contributed equally to juvenile Chinook salmon mortality in the studies reviewed. Therefore, for modeling purposes, five percent was chosen as the expected sorting mortality rate. Because survival rate is the complement of sorting mortality rate (% Survival = 1 – % Mortality), the expected sorting survival rate was 95%.

Because overall Sorting Efficiency is determined, in part, by the efficiency of each step during the sorting process, and because it is assumed that device and technician efficiency while sorting by size and species is high, overall Sorting Efficiency is limited by the survival rate of the emigrating juvenile Chinook salmon. An estimated average sorting survival rate of 95% was chosen based on the average of a range of reported combined mortality rates for collection, sorting, and transport. The survival rates estimated for sorting based on the estimated average sorting survival rate (absent survival rates for collection and transport) ranged from 90% to 99%. Therefore, for modeling purposes, best case, expected, and worst case Sorting Efficiency rates were estimated to be 99%, 95%, and 90%, respectively.

4.2. TAGGING SURVIVAL RATE

4.2.1 PIT Tagging Survival Rate

Definition of Terms

- PIT tagging involves surgically implanting a passive integrated transponder tag into the body cavity of an anesthetized fish.

- The PIT Tagging Survival Rate is the percentage of juvenile fish that survive the PIT tagging procedure, and is the complement of the tagging mortality rate.

Assumptions

- PIT tagged fish are exposed to handling stress and stress from tagging.

- Fish are anesthetized prior to tagging.

- Proper PIT-tagging procedures are followed.

- Fish that die only do so due to stress endured during the tagging process, not from other external sources of mortality or previous experiences.

- Latent mortality associated with the tagging procedure, or being tagged, is negligible.

Biological Justification

PIT tagging is a common procedure utilized for individual fish identification and estimation of growth, survival, and movement of juvenile salmonids. PIT tags, consisting of an antenna coil bonded to a pad and an integrated circuit chip, are relatively small (usually 11-32 mm) and are suitable for tagging relatively small fish, including juvenile salmonids (Roussel et al. 2000). As opposed to coded wire tags (CWT), which require sacrificing fish in order to visually inspect individual tags for subsequent identification of its characteristic code, fish tagged with PIT tags do not have to be sacrificed in order to identify codes. Identification can be attained through the use of a powered portable handheld tag interrogation system or a fixed tag monitoring system. Estimates of juvenile salmonid survival for the PIT tagging procedure vary, among others variables, by species and size of fish tagged.

Venditti et al. (2000) found that in the three years that tagging of naturally produced Chinook salmon of at least 115 mm in fork length (FL) in the Lower Snake River occurred, tagging associated mortalities were 3.2, 1.5, and 2.5 percent, respectively. Prentice et al. (1990) conducted a study to determine the minimum size at which a juvenile Chinook salmon could be PIT tagged and the relationship between fork length and survival. Tagged juvenile Chinook salmon ranged in size from 56 mm to 120 mm FL. Although individual fish size was reportedly as small as 56 mm FL, the smallest mean experimental group size was 66 mm FL. Survival of experimental groups ranged from 95 to 100 percent. Control group survival of fish handled but not tagged was found to be 99 to 100 percent. No association was found between survival and fish size. A similar study conducted using juvenile and smolt sockeye salmon (55 to 107 mm FL) found survival of PIT tagged juvenile sockeye salmon exceeded 96.5 percent in each experimental group. The mean length for each experiment group was 68, 82 and 99 mm FL. Control group survival exceeded 97 percent in three control groups (Prentice et al. 1990). In a study comparing survival of three different tagging methods at Columbia River dams, Prentice et al. (1990) found that PIT tagged juvenile salmonid percent survival at 14-days post-tagging was not measurably different from control groups. Several other field studies using PIT tagging to monitor individual juvenile salmonids reportedly tagged only juvenile fish exceeding 60 mm FL (e.g., Gries and Letcher 2002, Roussel et al. 2000, Hockersmith et al. 2000, Conner et al. 1998). Furthermore, Brakensiek (2002) reported apparent substantially lower survival rates for smaller tagged fish, suggesting one explanation may be a *"…chronic size-dependent mortality due to PIT-tagging…"*

Experimental mean juvenile Chinook salmon fork lengths for each of the studies examined were always greater than 60 mm. It is assumed that the preponderance of the 60 mm FL size threshold is either due to unacceptably high tagging mortalities or an inability to effectively tag fish smaller than 60 mm FL. A PIT tagging size threshold of 60 mm FL was established based on the literature review. Based primarily on the work of Prentice et al. (1990), we assumed that the tagging survival rate is between 95 and 99 percent, with an expected value of 97.5 percent. Thus, the best case, expected, and worst case values of PIT Tagging Survival Rate are 99%, 97.5%, and 95%, respectively.

4.2.2 CWT Tagging Survival Rate

Definition of Terms

- CWT tagging involves injecting a coded wire tag in the area of muscle, connective tissue and cartilage in the snout of an anesthetized fish.

- The CWT Tagging survival rate is the percentage of juvenile fish that survive the CWT tagging procedure, and is the complement of the tagging mortality rate.

Assumptions

- CWT tagged fish are exposed to handling stress and stress from tagging.

- Fish are anesthetized prior to tagging.

- Proper CWT-tagging procedures are followed.

- Fish that die only do so due to stress endured during the tagging process, not from other external sources of mortality or previous experiences.

- Latent mortality associated with the tagging procedure or being tagged is negligible.

Biological Justification

Coded wire tagging has been used as a major salmonid stock identification tool by many fisheries agencies, and was developed over 30 years ago for large-scale studies on migratory salmonids. Each year reportedly over 40 million CWTs are put into Pacific salmon and approximately 300,000 tags are recovered (Johnson et al 1990 *in* Solomon (2003)). Standard CWTs are a small length of stainless steel wire 1.1 mm in length and 0.25 mm in diameter. Half-length CWTs (approximately 0.5 mm long) are effectively planted into fish as small as salmonid fry (Solomon 2003). CWTs can be detected in live individuals; however, for proper deciphering of the tags characteristic code, the individual fish must be sacrificed. Estimates of survival of the CWT tagging procedure for juvenile salmonids vary among species and size of fish tagged.

Jonasson and Lindsay (1988) reported that during 1978 through 1980, the Oregon Department of Fish and Wildlife (ODFW) CWT tagged a total of 123,000 juvenile fall-run Chinook salmon from the Deschutes River, Oregon. The CWT-associated mortality for ranged from 1.1 to 4.2% (Brun 2003). In the spring of 2002, the ODFW captured over 12,000 juvenile Chinook salmon below and above Sherar's falls on the Deschutes River for CWT. The fork lengths of the juvenile Chinook salmon tagged ranged from 45 to 80 mm. Mortality for the CWT tagged fish below Sherar's falls was 1.06% and above Sherar's falls was 0.85% (Brun 2003).

CWTs were used to estimate survival of juvenile Chinook salmon emigrating through the San Joaquin River system as part of the Vernalis Adaptive Management Plan (VAMP) 2002 test period. Three groups of approximately 25,000 juvenile Chinook salmon were tagged with CWT. The associated tagging mortality rates were 0.48, 0.92 and 1.0 percent for the three groups (San Joaquin River Group Authority 2002). Over 80,000 juvenile Chinook salmon ranging in size from 36 to 95 mm FL were tagged using CWT in the Trinity River in 1991. An estimated 5,330 juvenile Chinook salmon died resulting from the tagging process, equaling a tagging mortality rate of 6.7 percent (Zuspan 1992).

CWT is an acceptable technique for tagging juvenile salmonids as small as approximately 36 mm FL. CWT's utility over PIT tagging is in the ability to mark large numbers of relatively small fish. Survival rates of juvenile Chinook salmon tagged using CWT ranged from less than one to approximately seven percent for the studies reviewed. Based upon this review, we assumed that the CWT tagging survival rate is between 95 and 99 percent, with an expected value of 97 percent. The expected CWT tagging survival rate was set at 97.5 percent reflecting the approximate average survival rates reported by Brun (2003) and SJRGA (2002). Thus, the best case, expected, and worst case values of CWT Tagging Survival Rate are 99%, 97%, and 95%, respectively.

4.2.3 Overall Tagging Survival Rate

Because PIT Tagging Survival Rate and CWT Tagging Survival Rate were equal, the best case, expected, and worst case Overall Tagging Survival Rate values were 99%, 97%, and 95%, respectively.

5.0 JUVENILE FISH HOLDING

5.1 HOLDING SURVIVAL RATE

Definition of Terms

- Holding Survival Rate is defined as the proportion of juveniles placed into holding facilities that survive to be subsequently transport, and is the complement of the holding mortality rate.

- Holding raceways are defined as long, narrow, permanent concrete, or transient floating steel structures adjacent to collection devices in which juveniles would be held for up to three days. One example was reportedly five feet wide by four feet deep by sixty feet long (Puget Sound Energy Unpublished Work; Puget Sound Energy Unpublished Work; USACE 2000).

- Typical net pens reportedly are made from 0.2-inch mesh nets. The nets are suspended from floating platforms and are typically 20 ft by 20 ft with a depth of 7 to 10 feet (Beeman and Novotny 1994). Pens of this size have been used to raise pre-smolt Chinook salmon at densities of 18,000 fish per pen (Beeman and Novotny 1994).

Assumptions

- Water temperature-related mortality is negligible; appropriate water temperatures would be provided.

- Flow through the holding area would be sufficient to maintain dissolved oxygen concentrations at 80% of saturation or higher; with the minimum dissolved oxygen content at no less than 5 ppm (Meehan 1991).

- Loading densities for net pens would not exceed 0.4 to 0.5 pounds of fish per cubic foot of water (Bell 1991).

- Loading densities for raceways would not exceed 1.0 pounds of fish per cubic foot of water (Bell 1991).

Biological Justification

The two most commonly used devices for holding juvenile salmonids reported in the literature reviewed are net pens and raceways; however, reported survival rates associated with each device differ slightly (Matthews et al. 1986a; Rensel et al. 1988).

The rearing and release of salmon using net pens has been practiced at a variety of projects geared toward increasing the survival of hatchery reared salmon after stocking, as well as for increasing the survival of salmon for the purpose of enhancing fishing and angling. The use of net pens has reportedly resulted in high survival during rearing and upon release, and has become a highly supported method (Commercial Salmon Trollers Advisory Committee website). Examples of the successful net pen projects include the Monterey Bay Salmon and Trout Project and the Central Coast Salmon Enhancement project. The Monterey Bay Salmon and Trout Project uses net pens to increase the survival of Feather River Hatchery Chinook salmon prior to their release. The Central Coast Salmon Enhancement project, a fishing and angling enhancement project, has found through coded wire tag studies that *"pen-reared salmon survive to enter the commercial and sport fisheries at exceptional levels"* (Commercial Salmon Trollers Advisory Committee website). A five-year study conducted by Rensel et al. (1988), evaluating the use of the marine net pens in Puget Sound, Washington, reported that juvenile coho salmon survival in net pens with 243 cubic meters of immersed volume averaged 98.4 percent.

Prentice et al. (1990) reports holding survival rates for control groups (groups of fish that are handled but not tagged) of PIT tagging investigations. Survival estimates for control groups reported by Prentice et al. (1990) are likely representative holding survival rates, in general. Survival rates for two control groups of 200 juvenile Chinook salmon with mean fork lengths of 77 mm were 99 and 100 percent over the 135-day test period. Survival rates for control groups of small presmolt, large presmolt and smolt sockeye salmon were 99.5, 98.5 and 97 percent, respectively. Survival of three steelhead and two fall-run Chinook salmon control groups, ranging in mean FL from 67 to 171 mm, were all 100 percent survival after a 14-day holding period. Control groups of yearling Chinook salmon and steelhead held at Lower Granite Dam had survival rates of 95 and 100 percent, respectively, 14 days post-handling. Control groups of age-0 and yearling Chinook salmon held at McNary Dam had survival rates of 96 and 86 percent, respectively, 14 days post-handling (Prentice et al. 1990).

The holding survival rate in raceways ranged from 86 to 100 percent in the literature reviewed. The mean holding survival rate for the investigations reviewed was 97 percent. In the single investigation reviewed for holding survival in net pens, the mean survival rate was 98.4 percent. Because the survival rates between net pen and raceway holding are similar, the expected, best and worse case values will apply to holding in both types. The reported range for holding survival serves as the basis for best and worst case juvenile holding survival. However, because some mortality is expected, 99% was chosen as the best case holding survival rate. Therefore, the best and worst case holding survival rates are 99 and 86 percent, respectively. The mean of the literature-reported holding survival values serve as the expected value, and was determined to be 97 percent. Thus, the best case, expected, and worst case values of Holding Survival Rate are 99%, 97%, and 86%, respectively.

6.0 JUVENILE FISH TRANSPORT

6.1 OROVILLE BARGE

6.1.1 Barge Survival Rate

Definition of Terms

- Barge Survival Rate is the percentage of juvenile Chinook salmon that survive being transported from the gulper collection facilities across portions of Lake Oroville to the truck loading facility, and is the complement of the mortality rate.

Assumptions

- Older barges used for fish transport have a capacity of 85,000 gallons of water and an inflow of 5,200 gallons per minute. Newer barges have a capacity of 100,000 gallons and an inflow of 10,000 gallons per minute. The holding criterion for barge transportation is 5 pounds of fish per gallon per minute inflow. Therefore, this allows a maximum of 26,000 and 50,000 pounds of fish for the older and newer barges, respectively (Koski et al. 1990).
- Barge capacity criteria will be observed.
- Barge survival rates depend on the number and size of juvenile Chinook salmon being transported, and the duration of time spent in the barge's tanks.
- Barge survival rates reflect only the impacts of being barged – latent mortality (mortality due to experiences prior to being barged) is assumed to be negligible.
- The barge survival rates for fish barged in Lake Oroville are not different from the barge survival rates for fish barged in the Columbia River system.
- Barge survival rates do not include subsequent delayed mortality resulting from barging-related stresses; this type of mortality is assumed to be expressed in subsequent model steps (e.g. life history stages).

Biological Justification

The reported barge transport mortality rates reviewed vary from less than one to approximately 30 percent, depending on the species, age and distance transported. The barge mortality rate at the Lower Granite Dam, Snake River collection facility was reported to be 1.0 percent for juvenile Chinook and 0.1 percent for steelhead (Hetherman et al. 1997 *in* Congleton et al. (2000)). Chinook salmon transported by barge from the Lower Granite and Little Goose dams to five miles below Bonneville Dam, on the Columbia River system, were reported to experience a mortality rate of 1.9

percent. The mortality rate for steelhead transported from these same locations was reported as 0.1 percent (Koski et al 1990). Preliminary survival was reported as 86 percent for juvenile salmon transported by barge from the Lower Granite Dam to Little Goose Dam in 1995 and a 70 percent survival rate was reported for juvenile salmonids transported to McNary Dam on the Columbia River during this same year (NW Fishletter 1997). The barge mortality rate for juvenile spring-run Chinook salmon transported from Lower Granite Dam to Bonneville Dam in 1982 was reportedly approximately 13 percent (Matthews et al. 1986a).

Barge transport survival rates were determined based on the reported mortality rates for the juvenile fish barging operations reviewed for the Columbia River system. Based upon this review, we assumed that the barge survival rate is between 70 and 99 percent, reflecting the range of barge survival rates reported in the studies reviewed. Because a barging program in Lake Oroville would require a shorter barging duration than the Columbia River program due to shorter distances required for barging, the expected value for barge survival rate was arbitrarily shifted towards a higher survival rate, and is estimated to be 95 percent. Thus, the best case, expected, and worst case values of Barge Survival Rate are 99%, 95%, and 70%, respectively.

6.2 TANK TRUCK

6.2.1 Truck Survival Rate

Definition of Terms

- Truck Survival Rate is the percentage of juvenile salmon that survive being transported downstream by tank truck, and is the complement of the mortality rate.

Assumptions

- Fish hauling tanker trucks have a rating capacity of 3,500 gallons of water per tanker and, at present the present hauling criterion of 0.5 pounds of fish per gallon. Therefore, a fully loaded tanker truck contains approximately 1,750 pounds of fish (Koski et al. 1990).

- Truck capacity criteria will be observed.

- Truck survival rates depend on the number and size of juvenile Chinook salmon being transported, and the duration of time spent in the tanks.

- Truck survival rates reflect only the impacts of being trucked – latent mortality (mortality due to experiences prior to being trucked) is assumed to be negligible.

- Truck survival rates do not include subsequent delayed mortality resulting from truck transport-related stresses; this type of mortality is assumed to be included in subsequent model steps (e.g. life history stages).

Biological Justification

The reported truck transport mortality rates reviewed vary from less than one to approximately 13 percent. The mortality rate for Snake River juvenile Chinook salmon transported by truck from Lower Granite Dam to Little Goose Dam was reported to be two percent (USACE 1993 *in* Ward et al. 1997). The mortality rate of Chinook salmon transported by truck from Lower Granite Dam to Bradford Island in the Columbia River system was reported to rise from 0.5 percent in 1988 to 0.9 percent in 1989 (Koski et al. 1990). Tank truck transport mortality for juvenile Chinook salmon transported from McNary Dam on the Columbia River was reported to range from 2.0 to 2.2 percent in 1982, 0.9 to 1.3 percent in 1983, 0.8 to 1.2 percent in 1984, 1.3 to 3.4 percent in 1985, 1.4 to 2.5 percent in 1986, 1.4 to 3.5 percent in 1987, 1.1 to 1.9 percent in 1988 and 1.6 to 2.0 percent in 1989 (Koski et al. 1990). The truck mortality rate for juvenile salmon transported from Lower Granite Dam on the Snake River to Bonneville Dam on the Columbia River in 1982 was reported to be approximately 12 percent (Matthews et al. 1986b).

Truck transport survival rates were determined based on the reported mortality rates for the juvenile fish trucking operations reviewed for the Columbia River system. Based upon this review, we assumed the truck survival rate is between 88 and 99 percent, reflecting the range of truck survival rates reported in the studies reviewed. The expected value for the truck survival rate was determined by averaging the reported values from the studies reviewed, and is 98 percent. Thus, the best case, expected, and worst case values of Truck Survival Rate are 99%, 98%, and 88%, respectively.

7.0 JUVENILE RELEASE TO ADULT CAPTURE

7.1 OCEAN-TYPE LIFE HISTORY

Definition of Terms

- Juvenile Release to Adult Capture Survival Rate includes survival rates for the following fish passage program elements: juvenile release, ocean survival, in-river adult immigration survival, homing, and ladder capture efficiency.

Assumptions

- Survival rates for juvenile release include mortality associated with release (i.e. predation upon release) and latent mortality associated with previous fish passage elements (i.e., capture at tributary mouths, barging across Lake Oroville, sorting, tagging, etc.).
- Sources of ocean mortality include, but are not limited to, predation by marine mammals, sport and commercial fishery harvest, and natural sources of mortality including disease.
- Ocean survival is highly dependent on ocean and climatic conditions.
- Other than catastrophic in-river events, factors determining in-river survival are reasonably constant (i.e. sportfishing harvest).
- Survival rates of returning FRFH adult Chinook salmon are representative of the entire Feather River Chinook salmon population. This assumption is consistent with recent findings by Nielsen et al. (2003) based on genetic analyses of Central Valley salmonid populations (i.e. hatchery and wild stock return rates do not differ substantially).

Biological Justification

The Juvenile Release to Adult Capture element of the model represents a broad period that was previously separated in the original SP-F15 Task 4 model. The original elements were juvenile release survival, ocean survival, adult in-river immigration survival, homing, and ladder capture efficiency. The elements were combined in because CWT data from the Feather River provide site-specific estimates for the overall survival from juvenile release to adult returns to the hatchery of origin. Data queried from the RMIS online database (http://www.rmis.org) provided data for 25 CWT tagging groups, representing 2,043 tags recovered at the FRFH from 1,586,237 tagged fingerling Chinook salmon released at various locations within the Feather River, including Live Oak, Gridley, Verona, and Yuba City. A pair of releases made directly at the FRFH were not included because their recovery rate was much lower than that observed for other groups. Based on these releases and recoveries the values for Juvenile Release to Adult Capture were 0.16%, 0.11%, and 0.07% for best case, expected, and worst case scenarios, respectively. However, these values warrant some correction for tag loss and expected differential success for wild salmon versus those raised in the FRFH. Tag loss occurs when tags are shed by fish, lost in the recovery process, or are damaged and rendered unreadable. According to DFG staff, tag loss generally can be expected to be less than 10% (pers. com. M. Erickson, 2004). Based on DFG's estimates of tag loss, the tag recoveries obtained from the RMIS database will be expanded by 10% to account for tag losses.

Hatchery produced salmonids generally are thought to have lower survival rates than comparable wild stocks, but the presence and magnitude of this difference appears to be case specific. Chilcote et al. (1986) estimated that fry to smolt survival of hatchery fish averaged 28% of that of wild fish in four brood years examined. Kostow et al. (2003) found that hatchery steelhead produced a third or less smolts per parent and a tenth or less adults per parent than wild steelhead. Among salmon, Bradford (1995) reported ocean survival for wild Chinook salmon of approximately 4%, while hatchery Chinook salmon survival rates often were less than 1% (Cross et al. 1991 i*n* Bradford (1995)). However, these patterns are not absolute. Several experimental studies have found few differences between the performance of hatchery and wild fish (Mudie et al. 1990; Rhodes and Quinn 1999). The reason that depressed success rates of hatchery fish appear to occur also is an important consideration. Studies by Chilcote et al. (1986), Kostow et al. (2003), and McLean et al. (2003) suggest that poor reproductive success (rather than poor ocean survival) may drive observed patterns among hatchery steelhead. In fact, McLean et al. (2003) were unable to find any significant difference between ocean survival of hatchery and wild steelhead. In a study of natural and barge passage of Snake River Chinook salmon, the data of Zabel and Williams (2002) demonstrated no difference in adult return rates between hatchery and wild Chinook salmon. Because disparities exist in the literature between reported ocean survival rates of hatchery and wild salmonids, no clear indication of an appropriate correction factor to apply to the reported ocean survival rates is evident. Reproductive success and early rearing is not included in this element of the model so it would be inappropriate to apply values from studies that found differences in these life stages (e.g., Kostow et al. (2003) and McLean et al. (2003)). Furthermore, most literature examined that compared hatchery and wild fish assumed that wild fish have reared in an environment that prepares them for and is comparable to the conditions they will experience while emigrating. However, the environment in the Lake Oroville tributaries is drastically different from that of the Feather and Sacramento rivers through which these fish must migrate successfully to reach the ocean. While natural rearing almost certainly enhances subsequent survival, reliably estimating the quantitative benefit to survival will require further dedicated study. For the purposes of the fish passage model, observed CWT based hatchery survival rates were expanded by 400 percent, 200 percent, and 100 percent for best case, expected, and worst case scenarios, respectively. Expanding the reported survival rates by up to 400 percent allows for a protective and conservative estimate of Juvenile Release to Adult Return rates. Combining these values with a reported estimate of 10% tag loss results in total estimates for Juvenile Release to Adult Return of 0.66%, 0.23%, and 0.08% for best case, expected, and worst case scenarios, respectively.

7.2 STREAM-TYPE LIFE HISTORY

Definition of Terms

- Juvenile Release to Adult Capture Survival Rate includes survival rates for the following fish passage program elements: juvenile release, ocean survival, in-river adult immigration survival, homing, and ladder capture efficiency.

Assumptions

- Yearling Chinook salmon have a higher survival rate than young-of-year Chinook salmon.

- Factors affecting survival of Juvenile Release to Adult Capture for Chinook salmon with a stream-type life history are similar to factors affecting the survival of Juvenile Release to Adult Capture for Chinook salmon with an ocean-type life history.

Biological Justification

The Juvenile Release to Adult Capture element of the model represents a broad period that was previously separated in the original SP-F15 Task 4 model. The original elements were juvenile release survival, ocean survival, adult in-river immigration survival, homing, and ladder capture efficiency. The elements were combined in because CWT data from the Feather River provide site-specific estimates for the overall survival from juvenile release to adult returns to the hatchery of origin. The analysis and literature review presented for Chinook salmon exhibiting an ocean-type life history also applies to those individuals exhibiting a stream-type life history. Ideally, a separate analysis using data collected from yearling sized fish would be conducted. However, comparable releases of hatchery reared yearlings were not available (yearling salmon are now rarely produced by Central Valley hatcheries), so a generalized correction factor for yearling sized fish was applied to the results for the ocean-type life history results. Dettman and Kelley (1987) analyzed ocean recoveries by size from tagged fish from 1956 to 1982 and found that yearling sized salmon were twice as likely to survive as fingerling sized salmon. Based on this observation, results from the analysis of survival of coded wire tagged juvenile Chinook salmon exhibiting and ocean-type life history are expanded by 200% yielding survival rates from juvenile release to adult capture of 1.32%, 0.46%, and 0.16% for best case, expected, and worst case scenarios of Juvenile Release to Adult Return for the stream-type life history, respectively.

8.0 ADULT HOLDING AND SORTING

8.1 ADULT HOLDING AND SORTING SURVIVAL RATE

Definition of Terms

- The Adult Holding and Sorting Survival Rate is defined as the percentage of adult Chinook salmon that are identified correctly (e.g., spring- versus fall-run Chinook salmon), and survive the sorting/handling process, prior to transportation to Lake Oroville or its tributaries.

Assumptions

- Personnel are properly trained in species identification.
- Differentiation of spring- and fall-run Chinook is based on time of capture.
- Male to female ratios in the collection facility are not biased, and be representative of the Feather River Chinook salmon population.
- Progeny of fish passage program fish cannot be identified visually.
- The adult holding period is short, no more than 2 to 4 days.
- If a longer holding period were determined to be more likely, then the estimates of the Adult Holding Survival Rates would likely correspondingly decrease.
- Adults Chinook salmon will be held at densities that do not exacerbate or result in increased stress or mortalities.
- Fish that are handled would be anaesthetized.
- Mortality during the returning adult holding period may result from conditions experienced or impacts incurred by immigrating adult Chinook salmon upon entry into freshwater through the time they are deposited into the holding pens prior to upstream transportation. This type of mortality is considered latent mortality, that is, it results from previous conditions or impacts, not those currently being experienced. For example, water temperature catch-and-release stress incurred while immigrating through the lower Feather River may result in mortality experienced while being held prior to upstream transportation. This mortality is reflected in the Adult Holding Survival Rate, despite the belief that the stresses that ultimately lead to death were experienced prior to holding.
- Mortality also may directly result from holding itself, including mortality resulting from disease, stress, fright, rapid environmental change, exhaustion and others.

- There is no difference between spring- and fall-run Chinook salmon responses to holding.

Biological Justification

Adult Chinook Salmon Sorting

Adult Chinook salmon are readily identified by external examination. Chinook salmon are the only salmonid that would appear in the collection facility with a black mouth and gums, large black spots on the back and both lobes of the caudal fin and a narrow caudal peduncle (DFG 2002). Current practices at the Feather River Hatchery define spring-run Chinook salmon as those fish ascending the fish ladder from September 1 through September 15 of each year. Chinook salmon captured subsequent to September 15 are defined as fall-run Chinook salmon (Kastner 2003). Given these factors, sorting by species should be 100 percent efficient and, by definition, sorting by Chinook salmon race is 100 percent efficient.

Adult Chinook Salmon Holding

Handling and releasing, with associated mortality due to stress, of adult anadromous salmonids is not as common as the handling and release of juveniles, therefore little information on the subject was reviewed. Bernard et al. (1999) reported a one percent mortality associated with trapping and fitting radio transmitters to adult migrating Chinook salmon (Bernard et al. 1999). From this study, a 99 percent survival of the sorting process could be inferred. In studying the effect of elevated holding temperatures on adult spring-run Chinook salmon reproductive success, Berman (1990) *in* McCullough (1999) had 100 percent survival of adults held at 14°C. Adult Chinook salmon held in a semi-natural pool at the Quinault Indian Nation's Salmon River hatchery for one and three weeks, exhibited survival rates of 100 and 90 percent, respectively. In general, survival in holding tanks is good (near 100 percent) for periods of up to one week, and survival of 75 percent for periods longer than two weeks in fairly common. These fish are generally handled once a week to determine readiness for spawning (pers. com. R. Rhodes, 2003).

Base upon the above information, for the purposes of model development, the expected Adult Holding and Sorting Survival Rate is assumed to be 98 percent. The best and worst case Adult Holding and Sorting Survival Rate is assumed to be 100 and 95 percent, respectively. The expected, best and worst case Adult Holding and Sorting Survival Rates are assumed to be applicable for a holding period of 2 to 4 days. Therefore, for the purposes of model development, the best case, expected, and worst case values of Adult Holding and Sorting Survival Rate are 100%, 98%, and 95%, respectively.

8.2 PIT TAG DETECTION RATE

The ability to detect a returning adult Chinook salmon that has been previously PIT tagged is dependent on the tag retention rate of adult Chinook salmon that were tagged as juveniles and the efficiency with which the PIT tag interrogation device used to detect PIT tagged individuals operates. An overall PIT tag detection rate can be determined from an evaluation of each of these components.

8.2.1 PIT Tag Retention Rate

Definition of Terms

- PIT Tag Retention Rate is defined as the percentage of PIT tags retained by returning adult Chinook salmon from the passage program that were tagged as emigrating juveniles.

Assumptions

- PIT tagging is performed by properly trained personnel.
- Sixty mm FL is the minimum size threshold for a juvenile salmonid to be PIT tagged.

Biological Justification

The Yakima River Project report 100 percent tag retention in juvenile Chinook salmon held for up to five months (Biomark website). Dare (2003) reported PIT tag retentions for Chinook salmon of over 99 percent. Ramstad and Woody (2003) reported tag retentions of 98 percent for sockeye salmon. Prentice et al. (1990), in a study of over 2,000 PIT tagged juvenile fall-run Chinook salmon, reported PIT tag retention frequencies between 99 and 100 percent for fish observed over a 2.5-month period. In another study examining PIT tagging several size classes of juvenile salmonids, Prentice et al. (1990) reported 100 percent tag retention and no tag migration within the peritoneal cavity over a 14-day period. In investigating the effects of PIT tags and the tagging procedure on maturing Atlantic salmon, Prentice et al. (1990) reported 100 percent tag retention in maturing and mature fish ranging from 61 to 80 cm. Seventeen percent of the female Atlantic salmon were reported to pass their PIT tags when spawned by hand (Prentice et al. 1990). In a study of 300 PIT tagged fall-run Chinook salmon held for a 570-day period, Prentice et al. (1990) reported a tag retention frequency of 98 percent. During the study period, the juvenile Chinook salmon underwent smoltification and were transferred to seawater (Prentice et al. 1990).

Based on the literature reviewed, the PIT Tag Retention Rate range reported was 98 to 100 percent retention. Thus, the best case, expected, and worst case values for PIT Tag Retention Rate are assumed to be 99%, 98%, and 97%, respectively.

8.2.2 PIT Tag Scanning Efficiency

Definition of Terms

- PIT Tag Scanning Efficiency is defined as the proportion of PIT tagged adult Chinook salmon that are collected in passage program facilities that are successfully identified as being PIT tagged.

Assumptions

- Initial implanting of PIT tags is done by properly trained personnel.
- Scanning equipment is not subject to failure and is properly used.
- The inability to detect a PIT tagged individual is only the result of: (1) the individual fish was never tagged; (2) the individual fish shed its PIT tag; and (3) the PIT tag is functioning improperly.
- 100 percent of PIT tags function properly.

Biological Justification

The Cowlitz Falls Fish Facility in Washington reports a greater than 95 percent PIT tag reading efficiency. This system automatically diverts fish to any of three different collection vessels upon PIT tag activation (Biomark 2004). In a review of the performance of PIT tag interrogation systems at Bonneville and McNary dams, Downing and Prentice (2003) reported detection frequencies of 98.2 and 99.2 percent for two different systems.

Based on the information reviewed, and for the purpose of model development, the best case, expected, and worst case values for PIT Tag Scanning Efficiency are assumed to be 99%, 98%, and 95%, respectively.

8.2.3 PIT Tag Detection Rate Summary

Combining the results from the PIT Tag Retention Rate and PIT Tag Scanning Efficiency results in a best case, expected, and worst case estimation of PIT Tag Detection Rate values of 99%, 97%, and 93%, respectively.

9.0 ADULT FISH TRANSPORT

9.1 ADULT TRUCKING SURVIVAL RATE

Definition of Terms

- Adult Trucking Survival Rate is the percentage of adult Chinook salmon that survive the process of being loaded into a truck, transported upstream and released into the reservoir or upstream tributaries.

- The survival rate is calculated by dividing the number of live adult Chinook salmon released upstream (in the reservoir or its tributaries) by the number of live adult Chinook salmon transferred from the holding facilities to the transport truck.

Assumptions

- Transport time short; decreased survival may result from increased trucking transport times.

- Chemicals used to reduces stress, slime loss, etc.

Biological Justification

"Biological Opinion on Effects of Issuing an ESA Section 10 Permit to the Corps of Engineers for Operation the Elk Creek Dam Trap-and-Haul for the 1998/99 & 1999/00 Fish Passage Seasons" (1998) reports that one to three adult coho salmon are injured or killed annually as a result of transfer to the transport truck and associated activities, including sampling for biological data and marking (NOAA 1998; Pacific Fishery Management Council 2003). Between 38 and 1053 adults are transported annually. No mortality associated with the actual trucking and release process was reported; this mortality rate is assumed to be zero. The survival rates associated with the above data were estimated to range from approximately 92.1 percent (35 out of 38 adults survive) to 99.9 percent (1,052 out of 1,053 adults survive). The estimated time-in-truck for these adults was 45 minutes.

During the October 1995 through September 1996 period, 2,196 spring-run Chinook salmon were transported via truck upstream in the lower Umatilla River. A total of 8 adult spring-run Chinook salmon died during trucking, equally a trucking survival rate of approximately 99.6 percent (Zimmerman and Duke 1996). The length of time required to transport the adult fish upstream was not reported, but assumed to be less than one hour.

Based upon the information reviewed, for the purposes of model development, the expected Adult Trucking Survival Rate is 96 percent (approximately the midpoint of the survival rates estimated for the Elk Creek program given above). The best and worst case Adult Trucking Survival Rate values are assumed to be 99 and 92 percent, respectively. Therefore, the best case, expected, and worst case Adult Trucking Survival Rate values are estimated to be 99%, 96%, and 92%, respectively, which are assumed to be applicable for a transport period of less than one hour.

10.0 ADULT FISH RELEASE LOCATION

10.1 MARINA ADULT RELEASE EFFICIENCY (%)

Definition of Terms

- Marina Adult Release Efficiency is the percentage of adult Chinook salmon that successfully migrate to spawning tributaries upstream of Lake Oroville after, upon capture at the Feather River Fish Hatchery ladder, being released directly into Lake Oroville.

Assumptions

- Sources of mortality upon release into Lake Oroville include sport fishery harvest and other natural forms of predation, disease and other natural forms of mortality and water temperature-related causes, especially resulting from being transferred from the truck into the warm epilimnion of Lake Oroville in early summer through the fall.

- Latent mortality may result from stresses incurred during lower Feather River immigration (e.g., related to water temperature, disease, catch-and-release and incidental hooking, etc.), handling and sorting at adult collection facilities, truck transportation and release into Lake Oroville.

- Sources of effective mortality (i.e., removal of adult Chinook salmon from the spawning population other than through death) include thermal barriers (either within spawning tributaries or resulting from a thermocline and warm epilimnion in Lake Oroville), which may prevent timely immigration into the spawning tributaries, and residualization (i.e., cessation of spawning-related activities and taking up residence in the reservoir).

- Fecundity and egg viability are dependent upon the thermal regime experienced and the reservoir residence time.

Biological Justification

Successful spawning of adult Chinook salmon released into Lake Oroville would require their continued migration through the reservoir into suitable tributaries. Continued migration of released adult Chinook salmon out of Lake Oroville to upstream tributaries would require appropriate water temperatures, reservoir surface elevations, and tributary inflow.

Because little information was obtained describing the potential effects on, and survival rates of adult Chinook salmon released into the Oroville Reservoir and allowed to volitionally migrate into spawning tributaries, it was assumed that studies in other systems including the Great Lakes and the Columbia River could potentially provide information applicable to the Oroville Facilities Relicensing efforts regarding the potential release of immigrating adult Chinook salmon into Lake Oroville.

Natural spawning of land-locked Chinook salmon, as well as other anadromous salmonids including coho salmon and steelhead, has been documented in the Great Lakes tributaries. Chinook salmon spawned in at least 10 Lake Superior tributaries during 1990 to 1994 (Peck 1996). The Wisconsin Department of Natural Resources reports that no successful natural Chinook salmon reproduction occurs in the Wisconsin tributaries to Lake Michigan, although adult Chinook salmon are harvested annually in 8 out of the 9 Wisconsin counties with tributaries to Lake Michigan (Wisconsin Department of Natural Resources, http://www.dnr.state.wi.us, accessed January 2004). Approximately 20 to 30 percent of the estimated total population of adult Chinook salmon and steelhead reportedly are naturally produced in Lake Michigan (NOAA Fisheries – Great Lakes Environmental Research Laboratory, http://www.glerl.noaa.gov, accessed January 2004). Furthermore, recent observations in Lake Huron suggest Chinook salmon successfully spawn gravel shoals, potentially increasing the spawning habitat available to Chinook salmon (Powell and Miller 1990). Although this information pertains to naturally reproducing populations and hatchery populations stocked as juveniles, it is reasonable to assume, based on the reports on Great Lakes Chinook salmon, that some proportion of adult Chinook salmon transported from the lower Feather River into Lake Oroville would successfully locate and ascend upper tributaries to spawn.

Adult Chinook salmon would be subjected to several potential sources of stress and mortality upon being transplanted into Lake Oroville, including latent mortality stresses incurred during lower Feather River immigration (e.g., related to water temperature, disease, catch-and-release and incidental hooking, etc.), handling and sorting at adult collection facilities, truck transportation and release into Lake Oroville, sportfishing impacts and harvest, disease, and water temperature impacts.

Sportfishing in Lake Oroville could potentially remove a substantial portion of adult Chinook salmon transplanted. For example, annual harvest of Lake Michigan Chinook salmon between 1986 and 1996 ranged from approximately 180,000 to 950,000 fish. During that same time period, harvest rates (number of fish per angler-hour) ranged from approximately 0.03 to 0.08 (Benjamin and Bence, in-press). Although Lake Michigan supports a potentially very different Chinook salmon fishery than would be expected in Lake Oroville, it provides an example of the potential popularity a Chinook salmon fishery could obtain in the reservoir.

Another potential source of effective mortality (i.e. adult Chinook salmon not continuing to migrate to spawning habitat) could be the presence of sediment wedges that occurred at 700 feet above MSL during DWR site visits. These sediment wedges could potentially hinder upstream migrating adult salmon from entering the tributaries after placement in the Oroville Reservoir when not inundated. According to analysis performed for SP-F3.1 Task 1A, upstream migration of adult Chinook salmon would rarely be hindered by sediment wedges located at approximately 700 ft msl. For detailed analysis of sediment wedge inundation frequencies see SP-F3.1 Task 1A Final Report.

Water temperature is one of the most important environmental parameters affecting the distribution, growth, and survival of fish populations. Lethal water temperatures influence fish populations by directly reducing population size, while sub-lethal water temperatures can influence fish populations through indirect effects on the physiology of individuals during different life stages.

Inappropriately high water temperatures in Lake Oroville tributaries may present thermal barriers to adult Chinook salmon migration, thus precluding them from spawning without directly causing mortality. Similarly, warm epilimnetic water in Lake Oroville during late spring, summer, and fall also may present thermal barriers to migration, restricting adult Chinook salmon to cooler hypolimnetic waters, effectively eliminating them from the potential spawning population Adult Chinook salmon planted in Lake Oroville may cease normal immigration and spawning behavior, a process known as residualization, and take up residence in the reservoir. Although documentation of residualization of upmigrating adult Chinook salmon was not located, residualization of juvenile salmonids is well documented (e.g., Muir et al. 1999, McMichael et al. 2001, Viola and Schuck 1995), and adult residualization remains a possibility.

Based on an extensive review of the literature, a set of water temperature index values for adult Chinook salmon immigration and holding was developed. One set of adult immigration and holding water temperature index values was established for all Chinook salmon run-types to reflect an evenly spaced water temperature range reported in the literature to provide be optimal, suitable, sublethal, or lethal during upstream migration and holding. The water temperature index values selected to evaluate the Chinook salmon and adult immigration life stage are 60°F, 64°F, and 68°F (Table 1). Although 56°F is referenced in the literature frequently as the upper water temperature limit required for upstream migration and holding, the references are not foundational studies, and often are inappropriate citations. For example, many of the references to 56°F are based on Hinze Hinze (1959), which is a study examining the effects of water temperature on incubating Chinook salmon eggs. Boles et al. (1988), Marine (1992), and NOAA Fisheries (1997) all cite Hinze (1959) in support of recommendations for a water temperature of 56°F for Chinook salmon immigration. Because 56°F is not strongly supported in the foundational literature, however, it was not selected as an index value. The lowest water temperature index value selected was 60°F, because in the NOAA Fisheries biological opinion for the proposed operation of the Central Valley Project and State Water Project, 59°F to 60°F is reported as, “The upper limit of the optimal temperature range for adults holding while eggs are maturing” (NOAA Fisheries

2000). NOAA Fisheries (1997) states, "Generally, the maximum temperature of adults holding, while eggs are maturing, is about 59°F to 60°F" and that the, "Acceptable range for adults migrating upstream range from 57°F to 67°F. ODEQ (1995) reports that, "…many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60°F." In addition, 64°F was chosen as an index value, because Berman (1990)suggests that effects of thermal stress to pre-spawning adult Chinook salmon are evident at water temperatures near 64°F and also because 64°F represents a mid-point value between the water temperature index values of 60°F and 68°F. Berman (1990) conducted a laboratory study to determine if pre-spawning water temperatures experienced by adult Chinook salmon influenced reproductive success, and found evidence suggesting latent embryonic abnormalities associated with water temperature exposure to pre-spawning adults occurs at 63.5°F to 66.2°F. Finally, 68°F was selected as an index value, because the literature suggests that thermal stress at water temperatures greater than or equal to 68°F is pronounced and severe adverse effects to immigrating and holding pre-spawning adults, including mortality can be expected (Berman 1990; Marine 1992; NOAA Fisheries 1997). Because significant impacts to immigrating and holding adult Chinook salmon reportedly occur at water temperatures greater than or equal to 68°F, it was not necessary to select index values higher than 68°F.

Table A10-1. Chinook Salmon Adult Immigration and Holding Water Temperature Index Values and the Literature Supporting Each Value.

Index Value	Supporting Literature
60°F (15.6°C)	Maximum water temperature for adults holding, while eggs are maturing, is approximately 59ºF to 60ºF (NOAA Fisheries 1997); Acceptable water temperatures for adults migrating upstream range from 57ºF to 67ºF (NOAA Fisheries 1997); Upper limit of the optimal water temperature range for adults holding while eggs are maturing is 59°F to 60°F (NOAA Fisheries 2000); Many of the diseases that commonly affect Chinook salmon become highly infectious and virulent above 60ºF (ODEQ 1995); Mature females subjected to prolonged exposure to water temperatures above 60°F have poor survival rates and produce less viable eggs than females exposed to lower water temperatures (USFWS 1995)
64°F (17.8°C)	Acceptable range for adults migrating upstream is from 57ºF to 67ºF (NOAA Fisheries 1997); Disease risk becomes high at water temperatures above 64.4°F (EPA 2003); Latent embryonic mortalities and abnormalities associated with water temperature exposure to pre-spawning adults occur at 63.5ºF to 66.2°F (Berman 1990)
68°F (20°C)	Acceptable range for adults migrating upstream range from 57 to 67ºF (NOAA Fisheries 1997); For chronic exposures, an incipient upper lethal water temperature limit for pre-spawning adult salmon probably falls within the range of 62.6°F to 68.0°F (Marine 1992); Spring-run chinook salmon embryos from adults held at 63.5ºF to 66.2°F had greater numbers of pre-hatch mortalities and developmental abnormalities than embryos from adults held at 57.2ºF to 59.9°F (Berman 1990); Water temperatures of 68°F resulted in nearly 100 percent mortality of Chinook salmon during columnaris outbreaks (Ordal and Pacha 1963)

A recent study completed by Peery et al (2003) examined water temperatures and passage of adult salmon in the lower Snake River in Idaho. Radio telemetry was used to monitor up-stream migrations of adult Chinook salmon and steelhead. The analyses showed a high correlation between travel times between dams and water temperature. Additionally, Peery et al. (2003) reported that salmon stopped up-stream migration when water temperatures at fish ladders approached 20^{o}C (68^{o}F). Water temperatures at a depth of one meter in Lake Oroville and the study area on the Snake River are compared in Figure 10-1.

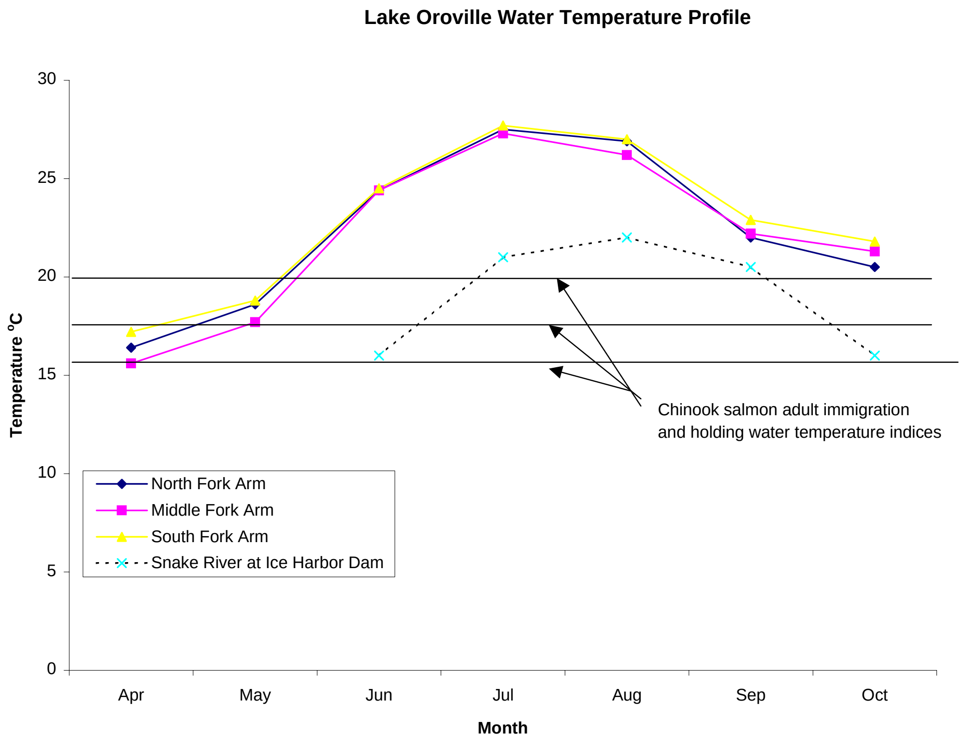

Figure 10-1. Lake Oroville water temperatures at a depth of one meter in the North, Middle, and South Fork arms compared to Snake River water temperatures at Ice Harbor Dam. Horizontal black lines indicate Chinook salmon immigration and holding water temperature index values.

Based on data used to create Figure 1, it would appear that a thermal barrier to migration into the upper tributaries of Lake Oroville would be in place until mid-October and perhaps into November. It also should be noted that the timing of the thermal barrier dissolution corresponds to low inflow from upstream tributaries and low reservoir storage levels that could potentially coincide with sediment wedge exposure periods.

From 1988 through 2000, Chinook salmon were stocked in Lake Oroville to promote a trophy salmonid fishery (DWR 2001). Landlocked Chinook salmon are known to complete their life cycle without going to saltwater. Self-sustaining populations of Chinook salmon have been established in the Great Lakes and a population has been established in Oahe Reservoir in North and South Dakota. The Oahe Reservoir Chinook salmon population does not spawn in the wild, due to a lack of spawning habitat in the tributaries to the reservoir. However, sexually mature males and females do return to the hatchery where they are collected and spawned in the hatchery environment (South Dakota Department of Fish and Game Fact Sheet website). Although some Chinook salmon have been observed in upstream tributaries to Lake Oroville, no spawning activity has been documented.

Because specific information that could provide a reasonable means of estimating the Marina Adult Release Efficiency was not located, for analysis and modeling purposes, arbitrary values for best case, expected, and worst case scenarios were selected. Based upon a review of the potential sources of stress and mortality adult Chinook salmon may encounter upon release into Lake Oroville prior to successfully locating and ascending a spawning tributary, the best case, expected and worst case values for Marina Adult Release Efficiency are 75%, 50%, and 25%, respectively.

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